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Subscriber Access Communication Systems

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DECLARATION

This dissertation has not been, nor is being currently submitted for the award of any other degree or similar qualification.

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ABSTRACT :

SUBSCRIBER ACCESS COMMUNICATION SYSTEMS

SYNOPSIS OF THESIS:

The objective of the project was to identify a market niche and specify the requirements for a system which would provide the opportunity to deploy more optical fibre based products. The area of the telecommunications network identified as offering the best opportunity to pursue this strategy was the local access loop of various Post and Telecommunications (P&T) authorities around the world.

The thesis identifies two market segments where the requirements exist for ;

a) first time provisioning of telecommunication services to the rural areas of the developing world

and

b) providing enhanced, flexible services to the business centres of the industrialised nations of the world.

The most prevalent subscriber and network signalling interfaces required to be developed on a network aiming to provide services in the access part of the local telecommunications network are identified. A rural model is developed, based on research carried out by the International Telecommunications Union (ITU) illustrating aspects such as typical network topology, growth scenarios and service requirements. The system solution designed to meet the needs of the end user in a rural environment is described at the system and sub-system levels. As a result of the system requirements identified as part of this project the engineering team within the company progressed to develop the Flexible Digital Access Multiplexer . The requirements are also identified for a Network Controller which would provide the P&T network operator with the capability to remotely manage and administer the Access System implemented in the region.

As a result of the system work and developments implemented to address the requirements of the rural market the company was well positioned to address the opportunity which arose to provide Flexible Access Systems to the Stock Exchange in the City of London during 1986. The Business Access System developed for use in this market is also described in this thesis.

The areas of improvement in the various network elements making up the Access System for any future applications are stated and the thesis concludes by highlighting the key achievements of the project.

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Glossary

AS = Access Switch used for switching Private Circuits
BAS = Business Access System
BT = British Telecom
BTNR = British Telecom Network Requirements
CAS = Channel Associated Signalling
CCITT = Consultative Committee International Telegraph and Telecommunications
CEPT = Committee of European Posts and Telecommunications
CODEC =Coder/Encode Circuit
CPD = Cable Products Division
CRC =Cyclic Redundancy Check
CSS = Common Channel Signalling
D channel = Data Channel
DASS2 = Digital Access Signalling System Number 2
DC = Direct Current
DC10 = Signalling System
DCE = Data Communications Equipment
DLE = Digital Local Exchange used for switching PSTN circuits
DPNSS1 = Digital Private Network Signalling System
DTE = Data Terminating Equipment
DTMF = Dual Tone Multi Frequency
E and M = Signalling System
EPROM = Eraseable Programmable Only Memory
FCS = Frame Check Sequence
FDAM = Flexible Digital Access Multiplexer
FDM = Frequency Division Multiplex
FW = Frame Word
GAS = General Assembly
GRP= Glass Reinforced Plastic
HD = High Definition
HDB3 = High Density Bipolar Coding Number 3
HDLC = High Data Link Control
HOMUX = Higher Order Mux
Hz = Hertz
ISDN = Integrated Services Digital Network
ISO = International Standards Organisation
ITI = Indian Telephone Industries
ITU = International Telecommunications Union
kbit/s = Kilo bits per second
kV = Kilo Volts
LAP = Link Access Protocol
MCI = Malicious Call Indication
Mbit/s = Mega bits per second

MCL = Mercury Communications Limited
MF = Multi Frequency
MTA = Metallic Test Access
MF4 = Multi Frequency System Number 4
NC = Network Controller
NFW = Non Frame Word
NM = Network Module
NT = Northern Telecom or Network Telemetry
NTI = Network Termination Interface
OSI = Open Systems Interconnection
PABX = Private Automatic Branch Exchange
PAD = Packet Assembly Disassembly Unit
PCB = Printed Circuit Board
PCM = Pulse Code Modulation
POR = Post Office Requirements
PSTN = Public Switched Telephone Network
P&Ts = Post and Telecommunication Authority
RAM = Random Access Memory
RAS = Rural Access System
RF = Radio Frequency
rms = Root Mean Square
SERC =Science Engineering Research Council
SNA = Systems Network Architecture
STC = Standard Telecommunications Company
STL = Standard Telecommunications Laboratory
SPM = Subscriber Private Metering
T1 = US Primary Transmission Rate
TS = Time Slot
UK = United Kingdom
USA = United States of America
X.21 = Data Protocol
X.25 = Data Protocol

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Chapter 1 Subscriber Access Communication System Project

1.1 Background

The strategic importance of telecommunications in national economies of the developing and industrialised countries of the world have been widely recognised and is described in studies such as Telecommunications for Development (2) and World-wide Telecommunications Development (8) which were undertaken by the International Telecommunications Union (ITU). These studies showed that an efficient and well developed telecommunication system was a basic requirement in any modern economy. The telecommunication network provides the infrastructure which enables industrial firms to keep in touch with their customers and suppliers, transport carriers such as airlines to provide reservation and service information, banks and financial institutions to transfer funds rapidly and it also enables millions of people to contact each other for business and social purposes. Telecommunications is therefore considered a major market for companies such as STC who sponsored a project forming the subject of this thesis as part of the SERC Teaching Company Scheme.

The objective of the project was to investigate the two principal facets of the telecommunications environment. These were;

(1) • The technologies available or those potentially capable of being developed by the company.

(2) • Identification of the needs of the market place from the telecommunications network operator and subscriber perspectives.

The aim of the project was to make an in-depth analysis of the above areas and link the right technologies together with the corresponding market need to produce products and systems which would enable the company to achieve larger sales for optical fibre cables. The industrial supervisor for the project who was also the Planning and Business Development Manager of STC-CPD, predicted the rapid decline in optical cable requirements in the trunk and junction areas of the transmission network and identified the local loop of the telecommunications network as the area where rapid and dramatic growth was expected to occur in the future.

1.2 Aim of Thesis

The aim of this thesis is to report the technical analysis of the issues involved in, and market evaluation of, the demand for telecommunication services in the subscriber access sector of the telecommunication network. The thesis also reports on the system level implementation of Access Networks, which were developed to meet the needs of rural subscribers in developing countries and also the needs of business customers in industrialised countries of the world to provide flexible, advanced services. In effect the thesis illustrates that there were two segments for Subscriber Access Communication Systems, which were;

(1) Basic telecommunication services for rural areas.

(2) Advanced services for business users.

1.3 Scope and Method

The first part of the project was directed to gaining an understanding of the subscriber access portion of the telecommunication distribution network. This was achieved by carrying out market and technical research activities which included the reading and critical evaluation of technical papers [3,16], holding interviews and discussions with a range of people involved in the telecommunications industry. The search also revealed some very high level technology trials which were underway in various parts of the world such as Biaritz, Bigfon,Hi-Ovis and HDTV[17] which were all concerned with the delivery of digital communication facilities as well as digital picture phone to the subscribers. As a result of the research, it was found that all of these projects were driven by technologists who ignored the commercial requirements of the end user in terms of functionality and cost. These projects therefore resulted in systems being developed which were technically advanced but unable to meet the end users requirements. It was an important requirement of this study to hold as uppermost, the needs of the end user in any implementation of a telecommunication system in order to achieve a viable solution which could be successfully deployed in the market place.

Part of this study was spent with the System Planning Group of Standard Telecommunication Laboratories developing networks which best illustrate the topology of rural networks which are most frequently found in rural regions of the world. Included in the analysis of the network were the planning of optical transmission systems with respect to link power budgets, fibre type, installation losses and teletraffic analysis of the network to ensure that the architecture was capable of supporting acceptable grades of service. Other considerations included environmental factors such as power availability, climatic control of cabinets in hot humid conditions and economic analysis of the proposed solution compared with competitive technologies such as small switches and multi-access radio.

The study also reviewed the socio-economic data and national economic development plans of a wide range of countries to establish prime market segments where the need was clear and readily addressable by the company.

Within the local telecommunication network, there exists a wide range of subscriber and network signalling systems . The study surveyed the large variety of subscriber and network signalling systems within the network to identify a subset which would enable the Subscriber Access Communication System to address at least 80% of applications in the market place.

Part of the project brief also included the identification of the key network control features required to support the remote operations, administration and management of the Access Network.

The research work addressing the above project requirements was carried out between October 1984 to September 1986 and was based on a multi-disiciplinary approach which encompassed systems engineering, combined market research and analysis to build a detailed picture of the access system requirements and to determine solutions for rural and business applications capable of satisfying these requirements.

1.4 Structure of Thesis

The thesis has been structured to include an abstract, a main section which contains eleven chapters and three appendices.

This chapter introduces the project and its associated background. It also identifies the aims and objectives of the project, scope and method of work undertaken. It finally concludes by describing the structure of the thesis.

Chapter 2 provides the market research and analysis undertaken at the onset of the project to identify the market needs which can be divided into rural and business application segments. It also describes the investigative market studies undertaken for access systems.

Chapter 3 provides an overview of the Access System and defines the evolving role of the PCM Multiplexer to meet the varied needs of an intelligent flexible multiplexer in access systems.

Chapter 4 identifies the sub-set of Subscriber Signalling Systems required by an Access System to enable it to serve 80% of the access applications found in the market place.

Chapter 5 takes the reader to the opposite end of the system to look into the network back to the host switch and identifies the key transmission interfaces and signalling systems required to meet the majority of identified market applications.

Chapter 6 proceeds to focus on the Rural Access System by stating the requirements, providing an illustration of a rural network. This model represents the key features of a large proportion of rural requirements in the market place.

Chapter 7 provides details to the reader regarding the implementation of the Flexible Digital Access Multiplexer. This implementation was realised by the development team in response to the requirements and design consideration identified in the earlier chapters.

Chapter 8 describes the requirements of a Network Controller which is used to operate, administer and maintain an access system.

Chapter 9 of the thesis describes the Business Access System(BAS) which evolved from the earlier work done on Rural Access Systems. The Business Access System (BAS) is intended for applications largely in demand by the business sector in developed countries.

Chapter 10 identifies improvements for future Access System components. It provides a critical review of the various sub-systems used in access systems, highlights specific deficiencies and provides suggestions for future improvements.

Chapter 11 contains conclusions which explains the links between the various aspects of the project and summarises the progress achieved in subscriber access communications.

The three appendices included in the thesis are provided for reference purposes to the reader. The first appendix provides a description of the OSI Reference Model around which the DASS2 Signalling system described in Chapter 5 has been based on. The last two appendices contain two papers which were published as a result of the research work undertaken in this project and are referenced in this thesis.

Chapter 2 Market Analysis

2.1 Introduction

This chapter describes the market research work undertaken to identify the two market segments for access systems. It provides an introduction to the initial marketing activities involving the ITU which led to the targeting of rural applications as the prime marketing opportunity. The specific needs of a rural telecommunication network are identified together with a definition of the services to be supported on an access network developed for use within this market area. Finally a market strategy and plan is developed to achieve a successful entry into the developing world focusing on China and India.

The British Telecom Local Network forms a very significant portion of BT's assets in the UK. To replace the existing dedicated copper distribution network from the local exchange to the subscriber premises involved very significant levels of capital investment. This indicated therefore that the modernisation of the local loop in the BT network would occur later in the eighties and as a result did not offer an immediate market opportunity. Hence the task of identifying an immediate market for optical fibre cables and associated electronic transmission equipment such as the Flexible Digital Access Multiplexer switched to overseas markets. As a result of preliminary market research carried out at the British Overseas Trade Board, a market requirement was identified for a telecommunication system in rural areas of the developing world. Further market research into this area identified the existence of a major world body commonly referred to as the Maitland Commission which produced the "Missing Link" report in December 1984 identifying major deficiencies in the provision of telecommunications to the inhabitants of developing countries, the majority of whom were found to live in the rural regions of their countries. China, India, South America, Africa and parts of the Middle East were considered as major customers for a cost effective, modern communication network designed for use in the rural regions of the world. To obtain more technical and market information, a visit was undertaken to the International Telecommunications Union (ITU) in Geneva, Switzerland. During the three day stay in Geneva a considerable amount of literature and information from key people in the ITU, Technical Co-operation Department and Consultive Committee on International Telegraphs and Telephones (CCITT) were obtained which clearly showed that should a suitable communication system for rural use be developed then an immediate market could be addressed by the company.

A rural network topology was identified and designed which used Flexible Digital Access Multiplexers, Optical Transmission Systems, Microwave Equipment and Solar Power. During most of 1985 the time was spent refining the product concept and producing technical and marketing information. Visits were made to Oman and Jordan by technical and marketing representatives in July 1985 and October 1985. Visits were also made to China to promote the Rural Access System.

During the middle of September 1985, a visit was undertaken to the ITU in Geneva to present a solution to the problem of providing Rural Communications in the developing parts of the world. The presentation was attended by senior members of the ITU and CCITT. A technical paper titled , " The Solution to the Missing Link"(Appendix 3) was presented in Yugoslavia at the Fibre Optics for the Developing Countries Conference during October 1985. The proposed Rural Access System was based on programmable Flexible Digital Access Multiplexers, Optical Transmission Systems and Network Management Systems. All of the above sub-systems enabled the implementation of a cost effective, flexible and highly reliable communication system. The paper was met with considerable interest from the telecommunication authorities attending the session who were responsible for the provisioning and planning of their respective national networks. The delegates were able to translate the benefits of the proposed rural access system to their particular needs in their respective countries.

During the end of 1985, STC changed its prime business focus from that of being a Switch supplier to become a Managed Transmission Systems supplier. The Flexible Digital Access Multiplexer's role in this change of business strategy was instrumental and the project was moved from Newport, South Wales to London. This move provided access to more engineering resources and raised the visibility of the project within the organisation. Funding and manpower resources were identified in a business plan which aimed to meet the business mission of being a major supplier of Managed Transmission Systems.

The Local Loop requirements for business customers in the UK was beginning to emerge as a strategic market opportunity.

Although the Flexible Digital Access Multiplexer was initially planned to address the Rural Market needs, it became very clear that a major opportunity existed in the UK for the product and associated systems, such as optical networks and network management products. BT in the UK was facing a major competitive threat from the newly licensed Public Telecommunications operator Mercury Communications Limited (MCL), who were methodically attacking BTs top 500 high revenue generating customers. MCL's brand new digital network based on Northern Telecom Trunk Switches, high capacity optical trunk and local distribution systems together with trunk and local microwave radio distribution offered very high quality and flexible services at low cost to the end user. MCL was also able to respond very quickly to their customers changing requirements and moods since they were not constrained by negative working practices and attitudes. All of these factors drove BT into a dynamic era which required them to instigate innovative and revolutionary ideas into the aging network to pump new vibrant blood into the company. Only by doing all of the above could BT hope to maintain its prestigious customers and slow down the erosion of its prized customer base.

The Flexible Digital Access Multiplexer and its network management capabilities were considered to be the vehicle on which BT would restructure its business private wire communications system. The Flexible Digital Access Multiplexer enabled remote configuration of circuit parameters such as line gain and circuit provision. BT were proposing to implement a layered network directed specifically towards its business customers; this network is referred to here in this thesis as the

Business Access System (BAS). The first contract was awarded in June 86 for a trial to be implemented on Heathrow Airport's complex to provide a Business Access System. The successful implementation of this project led the company to present the theme of access systems for both rural and business use at the 1986 Communicasia Exhibition in Singapore.

The following section describes the investigative market studies undertaken for access systems.

2.2 Rural Market

The investigations undertaken up to the end of December 1984 identified two distinct market segments for a system based on optical fibre cables, optical line systems and the Flexible Digital Access Multiplexer with its associated Network Management System. The first market segment occurred as a result of the findings and recommendations of the Maitland Commission. This was a body set up by the International Telecommunications Union at its annual meeting in 1982 to study the role of telecommunications in the economic development of developing countries. Many of the political administrations in the developing countries were allocating a higher priority to the development of their national telecommunication networks. Developing countries were focusing their efforts on telecommunications in order to increase both business communications and increase the availability of telephones to the majority of the population who were mainly distributed in the rural areas of the country. Finance for these projects were not easy to find, many developing countries depended on aid funding from industrialised nations.

These aid packages were constrained such that, the money provided had to be spent on products produced by the donor country. The climate prevalent during 1985/1986 indicated that funds for telecommunications projects would become more available than previous years. In the past the bulk of aid funding was superfluously spent on grandiose projects such as dam building, aluminium smelting and sugar refining primarily driven at the political level to obtain personal political prestige. Other aid agencies around the world such as World Bank and African Development Bank were considered as potential sources of finance for projects aimed in the area of telecommunications. It was hoped that the Maitland Commission recommendations would help to raise the priority of telecommunications aid funding with the above aid/loan agencies. The majority of developing countries were able to contribute partly to the financing of these projects by means of counter-trade. This form of trading enables the recipient country to use various commodity products such as sulphur, cement, beef and even fruits as payment rather than dip into scarce foreign exchange. Countries in the African continent faced more severe problems and were considered the ones least likely to provide effective counter trade products and were therefore heavily dependant on aid financing to undertake these projects. The January edition of a market research journal "Telecommunications Dollar[16] indicated a world rural telecommunications market of US$ 9 billion in 1986 for providing telephone services to rural and remote areas. Asia, South America and Africa were considered as regions with sizeable expenditure budgets.

2.3 Business Market

The second market segment identified was for a system which replaced the existing dedicated copper pair distribution network in the local loop of the industrialised nations. To clarify the term local loop please refer to Fig. 1. The local loop consists of the local exchange and copper cable network which establishes connection to the telephone subscribers. The Bell laboratories in the United States postulated a strategy which called for subscriber connections to be limited to a maximum transmission distance of 4km. This restriction of 4km allowed digital signals to be carried in the local loop by designing suitable line transmission characteristics which would be able to withstand the loss and delays inherent within copper cables. The vast majority of Post and Telecommunication Authorities (P&Ts) have established a substantial copper cable distribution network within their telecommunications network which represents a substantial investment in line plant. The idea of P&Ts writing off this asset and replacing them with a multiplexed overlay network using optical transmission was not expected to occur until the late 1980's ,early 1990's. It has to be noted that this conclusion was being made in 1984 at the start of this project. It was therefore felt that the requirements of the developing world should be addressed first where the market need was clearly identifiable and the developments required to produce a suitable product was considered to be well within the capability of the company. The technical knowledge and expertise built up within the company while addressing the rural market segment was expected to help consolidate the company's position to address the second more advanced market segment for Business Access Systems to be deployed in the industrialised nations.

2.3 Initial Project Focus

The project initially focused attention towards rural telecommunications where interest was being heightened due to lobbying by the ITU through research undertaken in the studies referenced in Chapter 1 ([2,3,8]. It was important that systems developed for use in the rural areas were economic and capable of future growth. The cost of providing service to rural areas averaged five times the cost of an equivalent service to the urban subscriber. It was estimated by Cable and Wireless system planners [2] that to meet all costs, including operations, maintenance, interest on loans and depreciation of plant for an urban subscriber would have to be one-third of the capital cost per subscriber, which in 1979 was taken as US$ 3,000. If this was extrapolated to account for the extra line plant for rural subscribers, it seemed very unrealistic for any rural subscriber to be lumbered with an annual telephone bill of US$5,000. At an initial glance it would seem attractive to cross-subsidize the rural service from the urban and international revenues, but this was not a feasible solution for many of the developing countries. High tariffs imposed on the low levels of international and urban traffic, would not contribute towards creating wealth for the countries economy. It was therefore essential to look towards technical developments for solutions to the problem of providing cost effective rural telecommunications.

2.4 Rural telecommunications

Rural telecommunications in developing countries can be characterised by long transmission distances, harsh climatic conditions and low population densities, lack of adequate mains power supplies and tremendous difficulty in predicting the medium term growth of telecommunication services.

Traditional rural telecommunication systems can rarely be separated from the very necessary subsidiary infrastructures required to establish the network. Access roads, civil work such as pole mountings and duct construction for subscriber distribution cables, power plants for equipment and skilled maintenance staff were some of the necessary sub-structures required.

It was often the hidden costs of these extra items which caused a rural telecommunication line to be five times the cost of its urban counterpart. The main objectives of a rural telecommunication network is the cost effective provisioning of an adequate service at minimum initial cost and also to provide the capability for modular expansion in the future as the rural economy grows and prospers.

2.4.1 Minimum Service

The question which immediately comes to mind is "What is the minimum service?". The answer which many experts in P&T and the ITU would provide is that a basic telephony capacity with the option of telegraphy or telex is the minimum service aimed at establishing a feasible communication network to serve the needs of the local inhabitants and any industrial ventures which might be established in the rural areas. The network must not be compromised in its quality of service, such as attenuation and signal to noise ratio. The rural network should conform to International Standards to allow the communication system to be integrated into both national and international networks. Therefore when one states that a minimum service is the primary objective of a rural network, it certainly did mean the type of communication services rather than providing a basic telephony network cobbled together using the lowest technological content. Any network situated in these areas had to offer reduced maintenance and be capable of using independent power sources such as solar or wind power. This meant that equipment power consumption and heat dissipation had to be kept down to the minimum possible. Even though it has been stressed that the immediate services required in the rural areas were telephony and telegraphy; the ability to enhance the network at a latter stage with other services such as data transmission facilities for computers would prove attractive for banks, post offices, government, railway stations, etc. This would enable the organisation to improve and provide an efficient service to their respective end users. The provision of slow scan television utilizing 2Mbit/s or 64Kbit/s could be added to the network at a latter stage to provide access to educational programmes and remote medical diagnostic facilities to hospitals located in urban cities. All of these extra services had to be capable of being integrated into the network in a modular fashion without having to change the fabric of the established network.

2.4.2 Planning Considerations

Before setting down the development criteria of a new product it was essential to understand the main considerations of the network planner who was responsible for stipulating the topology and type of technology to be used in the rural environment.

The system to be developed had to have the capacity to work in rural areas where basic infrastructure such as roads, power plant and maintenance staff were either inadequate or did not exist. The system had to be engineered to function in unfavourable ambient conditions which occured in the equatorial and tropical regions, where temperatures ranged between -20 C to +75 C, with humidity as high as 100%. The operational costs were extremely important and any equipment which was to be used in the rural network had to offer high reliability and consume the minimum off scarce maintenance resources. There were other items which were also found to contribute to the life cycle cost such as:

- Infrastructure costs of the site where equipment would be located, access roads, buildings, personnel etc...

- Equipment, cabinet to house system electronics for the subscriber network.

- Installation

- Maintenance

- Operation

All of these parameters contributed to the cost of ownership and running of a telecommunications network. It was considered desirable to incorporate the necessary features into the design of the Network to control the cost penalties incurred by all of these items. Equipment designed without attention to power constraints required a larger power supply which in turn required more fuel, more frequently. To transport this frequent demand for fuel an access road suitable to carry the load had to be constructed which immediately increased the infrastructure cost. Another example which illustrated this situation was, the ability to remotely test and supervise the system through appropriate electronic "hooks". Without this feature the telephone company had to transport skilled maintenance personnel with suitable test equipment and complete set of spares to each faulty unit. This in turn led to an increase in inventory for spares, test equipment, maintenance personnel and vehicles which would be used to transport trouble shooters to remote sites. If the appropriate, network management "hooks" were incorporated into the system at the design stage then the fault could be located down to card level, and the appropriate spare could be despatched to the remote site, where the only skill required would be to extract the faulty card and replace it with the working spare unit. By incorporating features such as low power consumption, remote equipment diagnostics, and centralised network management we could in fact help to reduce infrastructure and operating costs. The Telecommunications Network designed for the rural areas of the developing world had to be freed from many of the normal infrastructure requirements, such as roads, mains AC power supply and maintenance resources. By embracing the appropriate equipment philosophy and technical design criteria , cost penalties which were incurred by infrastructure equipment, installation, maintenance and operations could be effectively controlled.

2.5 Market Plan

2.5.1 Marketing Objectives

The principal need from the market place was for a cost effective Rural Access System which offered modular expansion capabilities. It had to be capable of evolving from a very simple network which provided access to basic telephony in the rural areas, through to higher capacity type networking which could serve the needs of a developing economy. The systems should be capable of expanding to these higher capacity modes and eventually to supporting broad band services via low capital expenditure. The prime marketing objective was therefore to develop a cost effective modular system, designed to function in the developing countries of the world. The world wide potential dictated a need for collaborative partners with the resources to assist STC, with both the marketing and installation of the systems. To ensure the appropriate levels of operational and system planning resources, it was imperative that another one of the marketing objectives should be to establish joint venture agreements with companies who possessed the necessary expertise in turnkey project management, which this type of system required. Many developing countries were found not to have the capability to implement major telecommunication projects and therefore looked to manufacturers who could provide the expertise to plan, install, commission, train and maintain the systems. This conglomeration of tasks is referred to as Turnkey Project Management.

2.5.2 Marketing Strategy

The system supplied should aim to cost significantly less than the estimated $5,000 U.S. total cost for the rural subscriber line, The system had to be cheaper to ensure a strong lending position in the market place. A target of $2,600 per line was estimated which also included operation, maintenance, interest on loans and depreciation costs. This cost target was arrived at by analysing the network topology illustrated in Chapter 5 with alternative competitive implementations such as small switches and time division multi-access radio systems described in the conference papers (Appendix 2,3)

Key markets were chosen in the initial phase, so as to ensure the maximum focus of tasks. The countries which were initially considered as offering the best potential for rural networks were China and India. Much more detailed information regarding the economic and political setting, current stature of telecommunications and announced plans and potential market size were required. In each of these countries it was also necessary to identify companies which possessed competitive threats to that being proposed. This information is discussed latter in this section. Developing countries such as China and India required technology transfer deals for equipment which formed a large proportion of their overseas procurement. The Rural Access System, had to provide at least 40% local manufacturing content. This was to be achieved in phases. The first phase would allow the assembly of certain parts of the system and the second phase would then pass the technology of the product to the purchasing organisation. The two phases were expected to stretch over a period of at least 5 to 7 years which would provide sufficient time for the company to enter into the market place with a second generation enhanced product for other more sophisticated applications.

2.5.3 Alternative Strategy

Should this main strategy prove to be unsuccessful or difficult to implement, then the alternative strategy would be to appoint distributors who would purchase sub-systems which made up the Rural Access System and STC, would play no role in Turnkey activities. Further territories not considered in the main strategy would also form part of the alternative strategy.

2.6 Countries

The countries chosen for the initial marketing thrust were China, India, Indonesia, Malaysia, Thailand, Turkey,Kenya and Oman with the primary focus being placed on China and India. These two countries were to be addressed by combining visits from STC personnel and local agents who were responsible for promoting the company's products in their respective regions. The following part of Section 2.6 provides the data obtained from a detailed market analysis undertaken for the two prime markets China and India.

2.6.1 People's Republic of China

China is the third largest country in the world in land area, spanning a distance of 4,000 kilometres from north to south, and 4,800 kilometres from east to west. More than one-fifth of the world's population lives in this vast, predominantly rural country. The population in China is heavily concentrated in the south whereas the western region is uninhabited by comparison. Table 1, displays a summary of the Economic Data[2].

Table 1

Area in sq. km.	9,561,000
Population	907,609,000
Population Growth Rate (1980-90)	1.3%
Total telephones	6,440,000

From the above data one can see that the telephone density in China is approximately 7 telephones for 1,000 people; i.e. 0.007%. This incredibly low number has to be increased significantly in the near future if China is to develop its socio-economic climate and generate national wealth.

The country is divided into 22 administrative provinces, including Taiwan. There are five autonomous regions: Kwangsi Chuand and Inner Mongolia, Niglisia Hui, Sinkiang Vighur and Tibet. The three centrally governed cities in China are Beijing, Shanghai and Tientsin. For purposes involving the telecommunications network, the two important organizational units in the country-side are the counties and communes. The counties, numbering about 2000 are the most stable unit. Each county has approximately 400,000 people. A county is subdivided into 74,000 communes which are the basic organisation for rural activities. Central ministries, state commissions and bureaus operate under the state commission and have partial control of the supply and allocation of labour, transport and communication, raw materials and manufactured goods. A number of agencies control the financial and trading activities of China, with the most influential being the People's Bank of China. The bank has the overall control of every aspect of the country's economic and monetary affairs, including the financing of foreign trade. During the 80's, China's government had an ambitious programme of rapid scientific and technological development.

China's economic problems were caused by limited hard currency reserves, mismanagement, and construction delays. China has a $2.5 billion US foreign debt and were therefore expected to assume a conservative stance in foreign debts by 1988 of no more than US $30 million.

The primary responsibility for telecommunications rests with the Ministry of Posts and Telecommunications (P&T) who are based in Beijing, this ministry also contains the Directorate of Telecommunications which contains the departments of Material Supply, Systems Engineering, Industrial Operations, Plant Installation and Technology.

Materials Supply has the responsibility for supplying materials and equipment to end users within the P&T. The systems engineering department has the authority to design and engineer aspects of telecommunications projects. The industrial department is responsible for operation and management of production facilities and factories under the P&T. The plant and installation department looks after the construction and installation of local projects. All major construction projects are handled by the department for Capital Construction. Science and

Technology holds control for all P&T research and development activities.

Organisations other than the P&T also have their own telecommunication facilities, such as the Ministry of National Defense, Ministry of Foreign Affairs and Ministry of Water and Power. The China National Machinery Import and Export Corporation (Machimpex), with head offices in Beijing is a major import ,export entity in the Ministry of Foreign Trade. This corporation holds the responsibility for telecommunications equipment and has the sole purchasing authority for telecommunications equipment from overseas countries. Where China are looking for complete technology transfer or the ability to produce major items of telecommunications equipment then these are co-ordinated and managed by the China National Technical Corporation (Techimport) which is also located in Beijing.

2.6.1.1 Status of Telecommunications in China

During the past 15 years, P&T services have lagged seriously behind the national economy which could not therefore contribute to the growth of the country's economy. The average installation time for a business telephone in Beijing , China's capital city is at best four months and for a rural telephone line to a commune is optimistically quoted as four years or more.

Most of the Chinese rural network which links 53,000 communes and 677,000 production brigade offices are of the basic kind which consists of open wire lines and terminates on manual switch boards serving magneto telephone sets.

Even though voice telephony represents the highest volume of traffic on the Chinese telephone network there are hardly any residential telephone services for private dwellers. At present rural communes with 15,000 or more people are served by a single telephone.

During the 1980-1985 planning period long haul high quality transmission systems and stored programme controlled digital switches were allocated the highest priority. It was anticipated that on completion of the trunk and junction modernisation work, the next stage of development would be the development of the rural network. This market was expected to open up slowly during 1987/1988 and remain open until the mid to late 90s. This market segment is expected to be much bigger than that for long haul transmission and SPC Switching which in 1980 was estimated to be US $278 million .

2.6.1.2 Market Strategy for China

To address this market , it was essential to enter into counter-trade agreements for products such as cement,sulphur, bauxite etc... and it would also be necessary to accept that up to 60% of the market share would have to manufactured locally.

2.6.2 INDIA

India has 695 million people which makes up 14% of the worlds population and the country occupies 2.4% of the worlds area.

Area in square km.	3,267,241
Population	694,555,000
Population growth rise	2.3%
Total No. of telephones	2,385,786

In 1980 the density of residential telephones was .87 telephones per 100 households while the business telephone density was expected to be 2.8 per 100 office workers. The country is predominantly agricultural and 80% of its people live in rural areas. Its population of 695 million people are distributed among some 580,000 cities, towns and villages spread over an area of 3.3 million square kilometres. India has one of the worlds highest population densities(212 people per square kilometre) . Of the 576,000 villages nearly 93% have a population of less than 2000 and the remaining 7% have 2000-5000 inhabitants. India has a federal form of government and a parliamentary system. The central government has greater power in relation to its 22 states and none union territories.

Each state is divided into districts, with the district being the basic administrative unit for such matters as revenue collection and law enforcement and it also forms the basic unit for the government's development planning. Districts are sub-divided into sub-units called "tehsils " each of which has its own headquarters in a small town. Thesil and district headquarters are natural foci for area telecommunications organisations. In the National Telecommunications Plans , a Secondary Area is made up of a number of districts while a Tertiary Area is defined as consisting of a number of Thesils. In the 305 Secondary Areas, telephone development varies considerably with 75% of these areas only having fewer than 2 telephones per 1000 inhabitants. India is keen to revitalize the traditional village councils and introduce grass roots democracy at the village level. The greater national planning impetus on rural telecommunications is reflective of this movement.

India's economy is the tenth largest in world terms. Although India exports goods such as ball bearings, tractors, diesel engines, sugar and textiles the economy is still dependent on agriculture. India's foreign trade is approximately $10-15 billion US a year with the US being its largest trading partner. India's long term economic development is very difficult to assess; it is constrained by problems of feeding her 700 million population, protection from excessive imports from the Industrialised countries and a strong caste system which prevents social and economic mobility.

The Ministry of Communications is responsible for providing telecommunication facilities in India. Services such as telephony, telegraph, telex, data communications, leased circuits are provided by the P&T except for some rare cases where telecommunications are licensed to private operators. At the field management levels,India is divided into territorial units called Telecommunication Circles,which are analogous to state boundaries. Each circle is headed by a General Manager

Telecommunications, to whom field divisional engineers report. In cities , District Managers are in charge of the telephone systems and they too report to the appropriate General Manager. In large metropolitan areas, telephone organisations are separate from the territorial circles with separate General Managers in charge.

For large projects, the country is divided into four zones, each with a General Manager. These four managers, together with managers in charge of specialized units, report to the P&T Board. The Board is responsible for the development and operation of both post and telecommunication facilities. The chairman of the Board is secretary of the communication Ministry and also is Director General of Posts and Telecommunications. The telecommunications Research Centre,TRC in New Delhi is the technological development arm of the P&T. Its major projects at present are electronic switching systems satellite communications and rural communications.

2.6.2.1 Status of Telecommunications in India

Only 9000 of the 575,000 villages in India have a telephone service. Many of these villages are in areas where sparse population, long distances, and poor roads make the expansion of telecommunications services difficult and costly. It is anticipated that India will allocate a budget of $3 billion U.S. over the period 1985 to 1990,towards the modernisation of the P&T network.($750 billion U.S. per annum.) The other licensed telecommunication operators such as the Indian Railways,Oil and Natural Gas Commission, Civil Aviation Department,Meteorological Department, Electricity boards, police authorities and a few others are estimated to have expenditures at 25% of the P&T's which represent a $700 million U.S. market.

Government approval at the cabinet level is required on major decisions regarding the introduction of new technology into the Indian telecommunications network. India is currently modernising its exchanges and long band transmission systems and will for the rest of this century concentrate resources towards the subscriber loop plant with particular emphasis towards rural telecommunications. India Telephone Industries (ITI) is a major domestic equipment manufacturer supplying exclusively to the telecommunications sector, where the P&T is its major customer. ITI plans to develop digital switches for use in rural areas and digital PABX's for business customers.

2.6.2.2 Marketing Strategy for India

It is almost certain that India will be reluctant to depend heavily on imports to modernize its network. It therefore seems reasonable to assume that the best avenue to follow would be one of collaboration with major domestic suppliers such as ITI to ensure a successful and long term entry into this market.

This chapter has presented the results of the market analysis work undertaken for this project. It has identified the existence of two market segments for rural and business applications within access systems. The next chapter shall provide a system application overview of the access network developed to meet these needs.

Chapter 3 System Overview

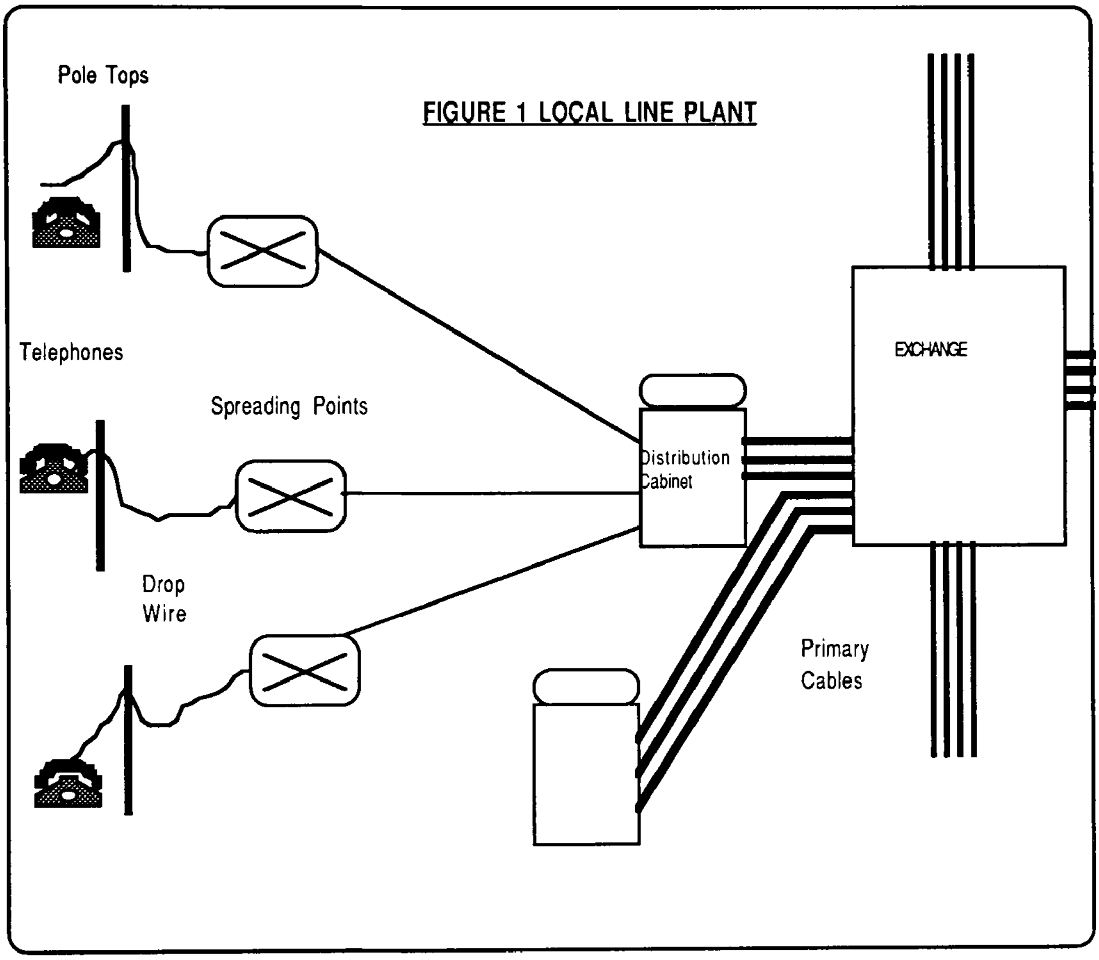
This chapter provides an overview of the market dynamics and technology factors which are driving traditional transmission products into the arena of Access Networks. The Heathrow Flexible Access System which was the first one to be deployed in the UK for BT is introduced here in this chapter.

Digital transmission systems such as the Pulse Code Modulated (PCM) Multiplexors are destined to play an ever increasing role in the development and evolution of the telecommunication network. The ever continuous drive to reduce cost, increase processing power and develop more compact products is creating a dynamic development environment which aims to deliver systems capable of providing a wide variety of services as economically as possible.

The synergy with digital switching systems are becoming stronger as remote multiplexing technology develops to the point where significant functionality is devolved away from the centre to the periphery.

3.1 Access Networks

Access Networks refers to that portion of the telecommunications infrastructure which is responsible for achieving connection between the subscriber and the exchange or switching system. The Access Network is currently dominated by traditional copper distribution cables from the exchange to the subscriber. The cable is normally housed in underground ducts up to a pole distribution point; from where aerial cables are employed to achieve the final drop to the subscriber. This shown in Figure 1.



In developed countries access to telephony services are taken for granted. Both the trunk and local networks are well developed with telephone distribution amongst the population reaching 80% or more. In North America, Western Europe and Japan it is now becoming the norm to have two telephones per household; one for the parents social use and the other for use by their children or for business purposes.

By contrast it has been shown in the previous sections that the underdeveloped and developing countries of the world have yet to achieve a 1% penetration of the telephone service amongst it's population.

3.2 Pulse Code Modulated (PCM) Multiplexors

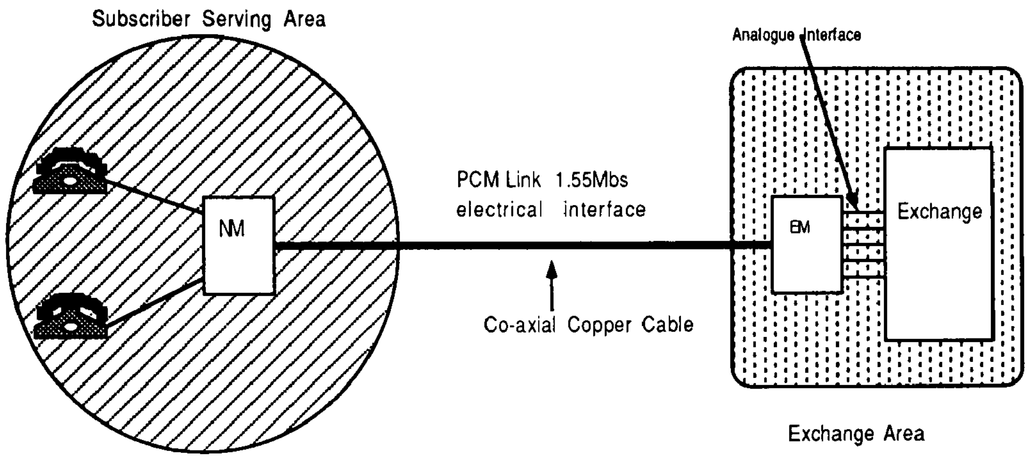
Pulse Code Modulated (PCM) Multiplexors were introduced in the early 60s to provide interconnections between trunk exchanges. Trunk Exchanges are major telephone circuit switching centres which serve a district of above 20,000 subscribers.

PCM transmission technology invented during the 1930s by George Hockham has made it possible to obtain acceptable transmission performance in the presence of severe cross-talk and noise. The relatively wide bandwidth required for PCM transmission has meant that until the advent of optical fibre transmission in the 1980's with its inherent high bandwidth capacity for carrying information, prior applications were restricted to inter-exchange connections to provide trunk circuits for telephone exchanges. Chapter 5 examines the structure and format of the PCM Multiplexer specified for use in the Access Network in more detail.

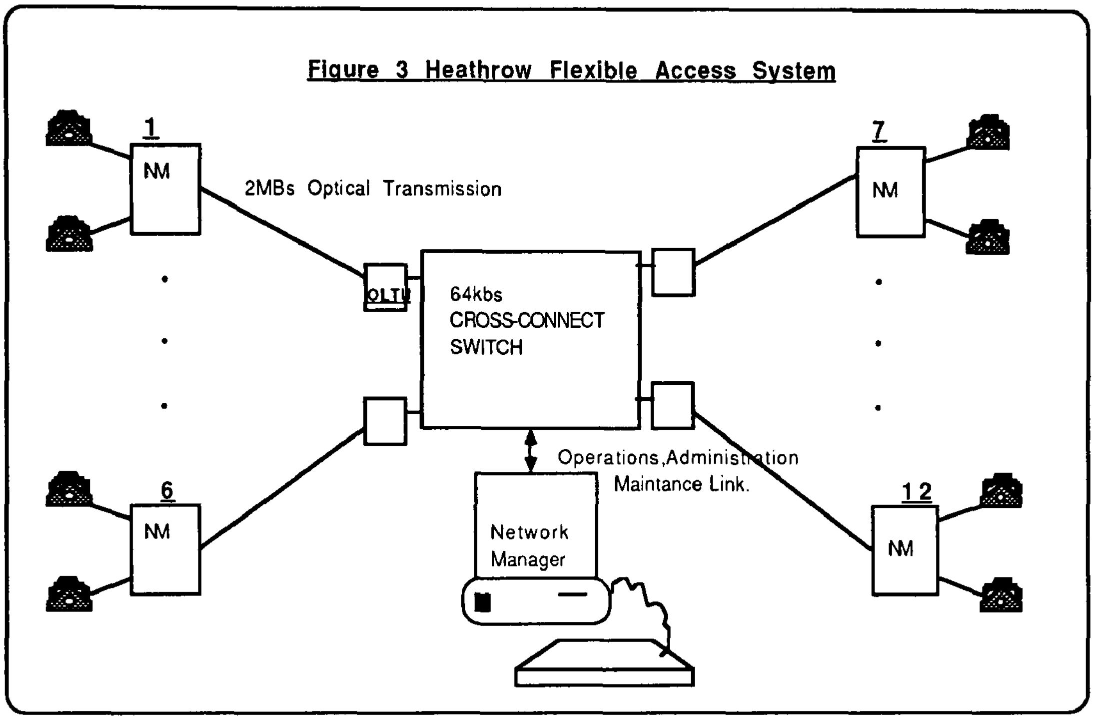
North America saw the first deployment of the multiplexer in the local loop as a straight digital pair gain extension as shown in Fig. 2. The term pair gain aims to describe the situation where connections to multiple subscribers are achieved using a single pair of physical wires. A single co-axial cable was used to connect

24 subscribers from an exchange to a rural subscriber cluster utilising a primary rate operating at 1.55Mbit/s .

Figure 2 DIGITAL PAIR GAIN EXTENSION



In the UK the first such application using multiplexers occurred during the mid 1980's when Digital Multiplexors were used to implement a distribution network on the perimeter of London's Heathrow Airport. The cable ducts underneath the runways of Heathrow Airport carrying telephone cable pairs were severely congested and the only means of providing extra capacity and flexible services was to employ optical fibre transmission systems based on Flexible Digital Access Multiplexors. The whole network was administered and managed using a computer based network management system as shown in Fig.3. The network could support both access from the Public Switched Telephone Network (PSTN) and Private Circuits (PCs). PSTN refers to telephone circuits provided by P&Ts via the National Network to subscribers served by the P&T. PCs refer to special telephone circuits with customised signalling to serve the needs of the P&Ts business customers.



The versatility and application flexibility of the multiplexer is considerably enhanced when combined with optical transmission systems. The system deployed at Heathrow Airport was a prime example of this. During periods of heavy traffic at a particular terminal the redundant capacity at the low usage airport terminal was switched over to drive more telephony services such as airport enquiry and security surveillance systems. The previous fixed copper telephone network was not able to offer this type of flexible traffic routing and service management during varying end user needs for telecommunication services. In the past BT would have had to install more cables which would have taken days to complete. With the Access System deployed at Heathrow

Airport, BT would be able to respond to customer requests instantaneously.

Diverse applications ranging from Rural Access System provision in developing countries to Flexible Access Systems in a major highly urbanised environment such as that in an airport of the developed world can be addressed by combining Digital Multiplexing technology with Optical transmission methods.

The following chapters will expand this idea and specify the major technical direction to be taken for signalling systems, network topology and control systems to achieve a viable Access Communication System.

Chapter 4 Subscriber Signalling Interfaces

The previous chapters have presented the market view and technology trends which are influencing the development of access systems. The following chapters will now turn the focus of the rest of this thesis to stating the system specifications and implementations required to realise a solution to address the needs of the market place.

A wide range of subscriber signalling interfaces are required to be supported on a telecommunications network. Many of these signalling systems have been established since the invention of the telephone itself e.g. magneto, while others have been developed to meet the varied needs of subscribers. It is the ultimate aim of the telecommunications planner to instigate a common subscriber signalling system capable of serving the needs of both audio telephony to computer data handling through the Integrated Subscriber Digital Network (ISDN).

The objective of this chapter is to present the major subscriber signalling interfaces which are found in the network. It was essential to undertake such an analysis in order to provide to the development team the prioritised list of signalling developments which had to be undertaken to ensure that the system developed was capable of addressing the main market areas. The subscriber signalling service mix was obtained as a result of surveys undertaken by means of questionnaires to P&Ts, the ITU and interviewing end users, to identify the access subscriber signalling requirements. A summary of this survey is presented in the following table.

Subscriber Signalling System	%
PSTN	
Direct Exchange Line (DEL) - Key Systems	75
PABX (Earth Call) Exchange Lines	10
Private Circuits	
2/4 Wire Audio	8
External Extensions DC 10 DC 5 (E&M) Magneto	4
Digital Circuits	2.5
Unspecified DC Signalling for Meters	.5

The following sections shall specify the key subscriber signalling systems to be developed for the Access System.

4.1 Audio Interfaces and Basic Signalling Interfaces.

The audio lines used in telephony are designated A and B wires, where in normal use the A wire is near end potential, and the B wire is negative relative to it. A four wire circuit has two sets of A and B wires: one set for outgoing audio , the other for incoming audio.

The term junction commonly refers to a connection between exchanges, and can be either 2 or 4 wire, with signalling being provided either on the audio wires or separately.

Electrolytic corrosion of the wiring is prevented by supplying 50 Volts DC negative relative to earth with trickle current of around 5-10 milliamps. This prevents the catalytic process which causes oxidization and therefore corrosion of the wiring.

4.1.1 Two wire and Four wire Configurations

All telephony is necessarily full-duplex in order to reduce equipment cost (this is especially the case at the local distribution level), only two wires are used to carry both the forward and return audio. The audio pair consists of a balanced line, to reduce hum and interference pick-up.

Where the line plant requires it, the audio will be split into the separate forward and return components, by a pair of transformers (or electronic equivalent) called a hybrid. Examples of components that require 4 -wire are:

Repeater amplifiers (often hybrids are associated with the amplifier, giving 2- wire connections between amplifiers).

Frequency division multiplexers

Digital CODECs

The telephone line must often carry other signals beside audio. For example, two wire subscriber connection must carry power for the telephone instrument, the ringing signal and control signals (e.g. dialing) from the subscriber , as well as tones to tell the subscriber about a connection being attempted. Lines between exchanges (including those between private branch exchanges (PBXs) and public exchanges) usually carry various types of signalling which are described in more detail below.

4.1.2 Line Protection

The telephony plant at both ends of a line must be protected against lightning - induced transients, and also against inadvertent connection to mains power supplies. In the case of a single telephone instrument, this is usually achieved with a simple discharge tube or spark gap.

At the exchange end , modern plant is more sensitive to excess voltage on the line, and a more complex protection scheme is required. It is usually implemented by a combination of:

- Spark gaps, avalanche diodes, Silicon Controlled Rectifiers (SCRs), diode bridges between the lines and earth (the diode bridge is associated with further diodes and capacitors so that the transient is transferred to the supply rails on the printed circuit board (PCB))

- Fuses, , small resistors in series with the lines. It is permissible to blow a fuse during connection to mains, but not during lightning.

An input impedance specification for exchange lines defines limits of the size of resistor that can be used in series with the line. Thermistors are attractive compared with fuses, since they are self-resetting: unfortunately they tend to deteriorate with age especially with 'use' and upset the line balance by changing their state unpredictably.

The protection circuitry must also withstand the bell signal (70V rms17Hz) without operating the safety cut off.

Electronic line interface devices have a minimum input of about 30V. The various requirements mean that there is a fairly narrow window in fuse and other device ratings.

4.1.3 Magneto Signalling

Essentially obsolete for public networks (except where line impedance is too high for DC subscriber signalling), magneto signalling is still used on private lines for fixed instrument to instrument connections, or with private manual exchanges.

No DC path exists, and the telephone instrument is powered locally. The ringing signal (60 to 80V rms AC at about 17Hz) is applied by hand generator or form a local supply, to call the distant party. Where call charging is in use, the user would 'ring off' with a short burst of ringing signal to signal the end of the call.

Alternatively, the instrument may have a DC path through when the handset is lifted: call charging can then be done by detecting this signal.

4.1.4 Loop-Disconnect Signalling

This is the most common form of subscriber signalling, and is also used in various modified forms for short-distance signalling between exchanges.

In the case of private subscribers, the line can be either essentially short circuit (looped) or open (disconnected). The idle state is disconnect, and the loop is applied when the handset is lifted. Dialing is by alternating the loop and disconnect conditions briefly, and the conversation is terminated by a sustained disconnect. Telecommunications authorities lay down standards for the impedances to be presented to the line by the instrument in each condition.

Some form of timing is required to discriminate between dial pulses and termination of the conversation. The condition of the line is not a complete indicator of its signalling state: its previous history needs also to be known, and is maintained in some form of finite-state machine (by relay sets, special electronics or stored-program system). This is also true for many other signalling systems.

The exchange applies ringing voltage (70V AC, 17Hz nominal) to the line to call the subscriber. A circuit called a ring-trip is necessary to detect the loop condition when the subscriber answers, and to disconnect the ringing voltage promptly. Whilst for private subscribers reverse signalling (from the exchange back to the sub) is performed by audible tones and ringing voltage, other methods are more appropriate for interexchange signalling. In this case, the power supply is generally at the called exchange, and the loop-disconnect done by the calling one. Reverse signalling(for line free, proceed to send, line answered, etc.) is then done by reversing the supply polarity, which can be detected by the calling exchange.

4.1.5 Multi-Frequency Signalling -MF4

MF4 is used between suitable push-button instruments and exchanges for dialing, and (in modified forms) between exchanges for passing selection information. Apart from dialing, MF4 instruments are identical to loop-disconnect ones. A small saving is achieved within the instrument bell circuit, as it is not necessary to prevent bell tinkle during dialing.

MF4 is a dual one-out-of-four tone system, so that two tones sound together. One is chosen from 697,770,852 and 941 Hz, the other from 1209, 1336, 1477 and 1633 Hz, giving a total of 16 possibilities. Ten are used for dialing, the others can be used for special functions.

Many of the previous comments about ringing and ring-trip, and about the need for a state machine for signalling, apply to this type of system. Since they are in the audio band multi-frequency signals may be passed directly through some types of exchange and line plant without interpretation if desired.

4.1.6 Additional Features

Many additional features can be made available to subscribers, such as:

- Exchange call-back, usually performed by earthing the B wire.

- Shared lines, ringing between the A-wire and earth for one subscriber, and between the B-wire and earth for other. To call the exchange, the subscriber presses a call button, which earths the corresponding wire.

- Subscriber Private Metering (SPM), either by a pulse of 50Hz longitudinal (= common mode) in UK,Australia, or 16kHz transverse (= differential) in Europe etc.

- Malicious Call Indication (MCI), by earthing the A-wire or the B-wire. (Sensing an earth on the A-wire is not easy with a single supply, since it is normally at earth potential anyway).

- Coin box vandalism alarm, by earthing both wires outside the speech path.

• Remote P-wire, often supplied to police, etc to hold the set-up of malicious calls while they are traced through an exchange.

• Pay-phones: The exchange reverses the DC in the line to indicate payment is required, and the line is looped with 5 k ohms in series when a coin is inserted.

4.1.7. Private Branch Exchange

In addition to normal subscriber features, PBXs require an indication from the exchange that the conversation has ended. This is provided by the exchange open-circuiting both the A- and B-wires for a short period after clear-down. The PBX detects this without drawing enough current for the exchange to sense a loop condition.

Some (UK only) PBXs also use earth calling instead of detecting dialing tone. The sequence is :

Idle Exchange	Exchange: -50V to B-wire,A-wire open-circuit
PBX initiating call	PBX:earths B-wire
Proceed to send	Exchange: normal feed (i.e. earths A-wire)
Dialing	PBX: normal loop-disconnect
Clear-down	Normal from PBX. Exchange: A-, B-wires open circuit briefly.

4.1.8. Audio-only and DC Wetting

There is a requirement for telephone quality audio only links, for example, for fixed connections, or where the signalling would be via separate wires. Some audio-only line plant requires a standing direct current for contact wetting on the lines: this current has the effect of keeping certain types of contact free of corrosion which could otherwise cause distortion to the audio. Currents of the order of a few milliamps are common.

Provision of DC wetting often involves having a standing DC in transformer windings, which may require a longer core, or a magnetic material with higher saturation flux.

4.1.9. DC10 Signalling

This is an inter exchange signalling system that works over a 2- or 4-wire junction. There are four signalling conditions:

A-wire earthed, B-wire at -50V.
B-wire earthed, A-wire at -50V.
Both wires earthed.
Both wires looped together, but not earthed.

In the 2-wire application, signalling can only take place when there is no conversation in progress. In the 4-wire application, the two wires above are connected to the phantoms (i.e., the centre taps of the line transformers), and in this case, signalling is always available.

4.1.10. E and M Signalling

This was originally an inter-exchange signalling system, using extra wires in addition to the audio lines, which is used in some systems between the junction output of an exchange and the line transmission unit. The M (stands for mouth) wire or pair of signals in the forward direction, and E (ear) in the reverse direction.

The E signal can be either open-circuit or earthed, and the M signal either at -50V or earth. Alternatively, where line pairs are used (over long runs between plant), the conditions of each pair can be either open-circuit or looped.

E and M signalling is an old standard, originally from Bell Telephones, to standardize the signalling interface between switching and transmission plant. It is used to pass line states between plant (e.g. idle, caller off-hook, clear-down in forward direction, and proceed to send, call answered in reverse direction), and also to pass dial pulses if required. The line plant will generally convert the E and M signals into a suitable form for transmission (examples include phantom DC, tone or digital).

The term 'E and M' is now applied to a range of signalling types that use a separate pair of wires (or two pairs) which are completely separate from the audio or data path.

4.1.11. AC15 Signalling

AC15 signalling is a voice-frequency system for inter-Private Branch Exchange (PBX) signalling on 4-wire circuits, so that forward and reverse signals are handled separately. A single tone of 2280 Hz is used in both directions.

The tone is present continuously on idle circuits (provides self-checking). The tone is removed in the forward direction to indicate off-hook. Tone present in reverse direction indicates proceed to send, then pulses of 2280 Hz are sent forward. Removal of reverse tone indicates called party answering. Short pulses are also used to signal charging information.

4.2. Data Interfaces

There are several different data interfaces that are designed to be multiplexed directly into the 2Mb/s system. The most common are described here.

4.2.1. Codirectional G.703

G.703 is a system for transmitting bidirectional data at 64 kilobaud down a single pair (or 2 pairs) of wires, without any signalling. The clock for both directions is sent to the terminal from the communication equipment in an embedded form.

Each bit of the data is sent as a block of 4 bits at 256 kbits/sec:

'1' is sent as a block 1100

'0' is sent as a block 1010

This is then converted into a bipolar line code, by sending alternate blocks as positive going and negative going ones. The line polarity is also reversed at the end of every 8 blocks (giving two successive blocks of the same polarity - termed a line violation) corresponding to the end of a byte at 64 kb. No DC component is present, allowing the use of transformers in the line.

A line hybrid very similar to that used in an audio circuit is used to convert from 4-wire at the line drivers and receivers, into a 2-wire connection to the subscriber.

4.2.2. X.21

The full X.21 interface contains control lines (similar to RS232, etc.) and separate data in both directions, as an 11-wire connection.

The wires between the terminal (known as the DTE - Data Terminal Equipment) and the Data Communication Equipment (DCE) are :

G(1 wire)	signal ground connection
T(pair)	data from DTE to DCE
R(pair)	data to DTE from DCE
S(pair)	common clock, from DCE
C(pair)	control from DTE to DCE
I(pair)	indication to DTE from DCE

The clock is again fed to the terminal from the communications equipment.

4.2.3. Integrated Subscriber Digital Network(ISDN)

ISDN extends a 144 kilobaud full duplex link to the subscriber, over a single pair of wires. This is connected to a Network Termination Interface, (NTI,)at the subscriber's premises. The NTI converts the 2-wire link into a 4-wire interface containing the two 64 kilobaud duplex channels (known as B channels) and a 16 kilobaud (D) duplex channel. ISDN is sometimes also termed the 2B + D interface.

The B channels are transparent through the exchange system. The D channel supports an HDLC type packet protocol.

The D channel is used for signalling, supporting multiple devices of different types, requests for a particular device type, polling for free devices and many other features. In addition, it can optionally be used as the subscriber interface to the Packet Switching System.

To recap, this chapter has provided the sub-set of signalling systems required to interface at the subscriber side of the access network to achieve acceptable market coverage. The following chapter describes the signalling requirements to achieve network side interface and therefore deals with aspects such as PCM structure and signalling formats within time slot 16.

Chapter 5- The Multiplexer in the Network.

The previous chapter describes the signalling interfaces required at the subscriber side. This chapter describes the signalling system employed to transmit the subscriber side information to the network side for onward processing at either the host switch interface for PSTN circuits or the opposite end of a Private Circuit (PC). Once again the aim here was to identify the prime technical requirements which existed for an access system to interface into the P&T network toward the host switching systems. Without stating the specific requirements , the developers would not have been constrained to interface via standard PCM line transmission systems and network signalling systems such as Channel Associated Signalling (CAS), AC 15 and Common Channel Signalling System all of which are defined in this chapter.

The PCM structure and the coding scheme used for relaying PCM data is also described in this chapter together with the three most commonly employed network side signalling systems.

5.1 PCM Time Division Multiplex

5.1.1 Pulse Code Modulation (PCM)

Pulse Code Modulation in general describes a system whereby information is transmitted by means of coded digital signals. In the telephony context it refers specifically to the transmission of audio by means of sampling and subsequent digital encoding.

CCITT defines a standard in which band limited audio is represented by 8 bit coded samples repeated at a rate of 8000Hz .

The coding scheme is in general non linear. The CCITT recognises two coding schemes: .i.A-Law; (in common use in Europe) and .i. u Law ;(used in the .i.USA;). For international transmission A-Law is preferred. In the A-Law coding scheme, the 8 bits of data are used as follows:

bit 1 (msb)	Sign bit, 1=positive, 0= negative
bits 2- 4	3 bit segment value or exponent
bits 5 - 8	4 bit mantissa

A linear sample is quantised in accordance with the quantisation Law (A-Law) and the resulting value is subsequently encoded . The encoding allows 4 bits of mantissa and 3 bits of exponent. This gives an inherently logarithmic encoding law. Even bits are inverted from the above to give the final A-Law values. This ensures that the no audio condition is not represented by a zero code.

U- Law uses a similar encoding scheme, except that it deviates from the mantissa/exponent form at low signal levels to give an improved dynamic range.

5.2 High Density Bipolar Code No. 3 (HDB3)

HDB3 is a coding scheme used for the transmission of data and associated timing information down a single wire pair (a so-called co-directional interface). In addition to allowing a clock signal to be extracted at the far end, the code has the attractive feature that regardless of the data transmitted, the signal spectrum contains no DC component. Transformer coupling may therefore be used.

Information is transmitted using one symbol per bit which can be zero (Z), positive level (+) and negative level (-) (a pseudo ternary code). Binary '0's are transmitted as space Z. Binary '1's are transmitted as a mark which is alternately a + or a -. This ensures that there is no net DC component on the line. To allow timing information to be extracted when long sequences of '0's occur in the input data, strings of four '0's are encoded as a sequence X Z Z V, where V intentionally violates the rule of sequentially alternated marks and X is a space or non-violating mark which ensures that the polarity of V alternates for each set of four '0's thus encoded.

The receiver detects violations to decode sequences of four '0's and can guarantee to see a mark at least one bit in four. The timing of this mark can be used by a flywheel circuit to extract a receiver clock signal.The HDB3 coding scheme is described in annex A of CCITT recommendation G.703.

5.3 CEPT 30 Channel PCM Interface

The European standard for primary level (ie. first level of multiplexing) multi channel PCM systems is the 30 channel structure defined in CCITT recommendation G.732.

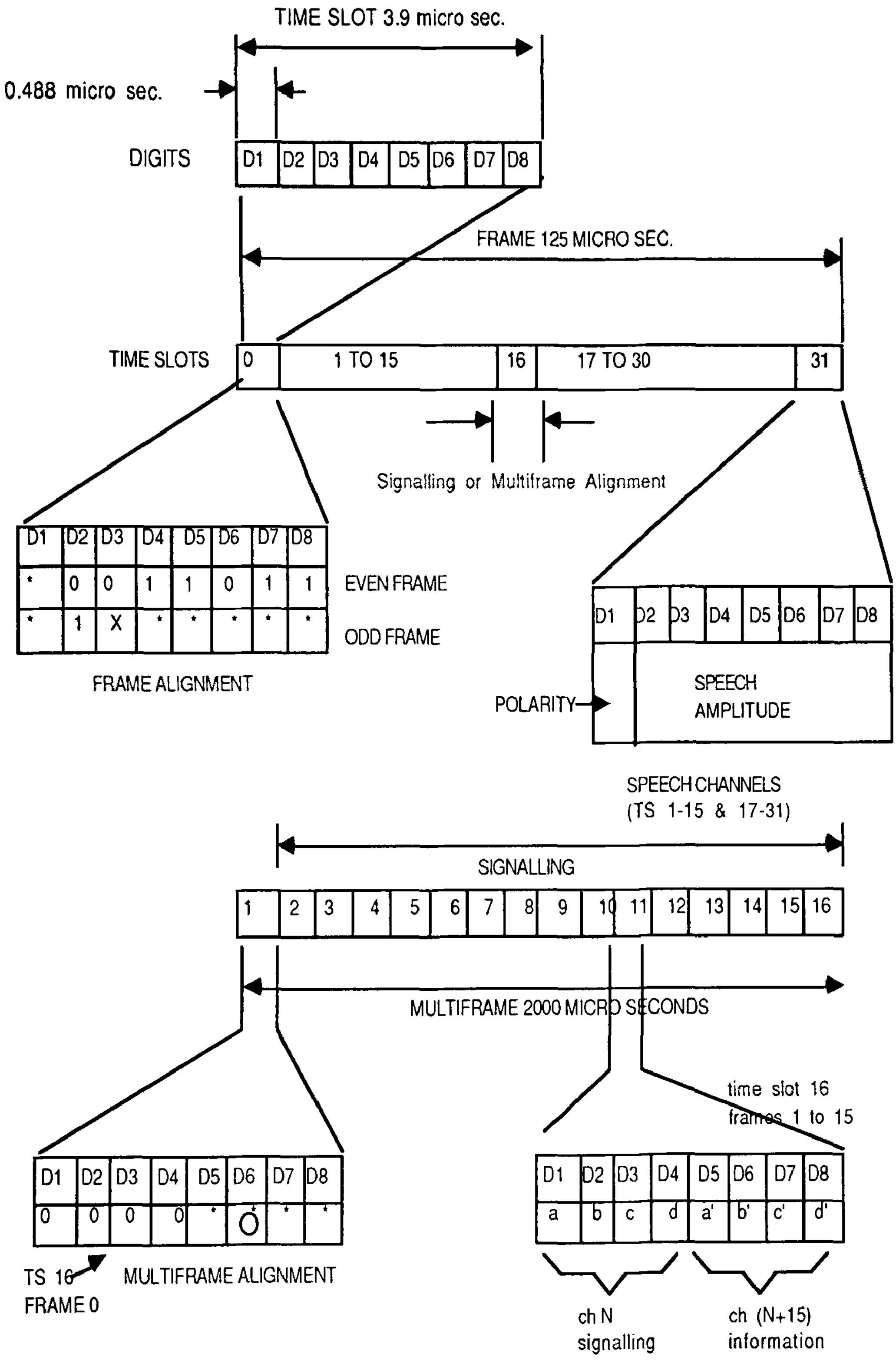
The basic bit rate for the system is 2048kbit/second. The data is encoded using HDB3 code described above. Multiples of 256 bits are grouped into a frame. Each frame is subdivided into 32 timeslots each of 8 bits, numbered 0 through 31. Frames are therefore repeated at an 8000Hz rate. Within a frame, timeslot (TS) 0 is used for alignment to the serial data stream and provides a number of spare bits for general use. Timeslots 1 through 15 and 17 through 31 provide 30 separate data channels. Each of these channels provide a data rate of 64kbit/s. These channels can contain arbitrary data or can carry a single audio signal coded using the A-Law coding scheme. TS16 is used to carry signalling information for all of the 30 channels. If signalling is not required, or is carried out by another means, TS16 can be used as a 31st channel.

Timeslot 0 is used for alignment to the serial data stream. Every second TS0 contains the frame alignment bit pattern 0011011 in bits 2 to 8 of the time slot. Bit 1 is unused. Frames containing the alignment pattern are turned Frame Word (FW) frames. Intervening frames referred to as None Frame Word (NFW) frames contain a 1 in bit 2 of TS0, an alarm bit in bit 3 and leave all other bits unused. During frame alignment, this alternating pattern of fix bits must be located. There is no mechanism which prevents normal timeslot data masquerading as a frame alignment signal, although in practice changing timeslot data is unlikely to provide a maintainable spurious alignment.

The alarm bit within alternate TS0 slots are used to signal a failure to downstream PCM equipment. A further mechanism of indicating alarm conditions to downstream equipment is via the AIS (All 1'S or Alarm Indication Signal) which is sent by sending octets of 11111111 either in TS16 or in all timeslots (CCITT defines TS16 only). One or both of these alarms may be raised according to the nature of the alarm condition. The AIS has the sometimes undesirable effect with certain signalling systems of clearing down calls. This may not be appropriate for short term faults.

A summary of the frame structure is shown in Figure 4. This figure also shows the multiframe arrangement that is recommended for channel associated signalling which is discussed in detail in section 5.4.

Figure 4 PCM Structure



* = SPARE, MAY BE USED FOR DATA, OTHERWISE FIXED AT 1

X = NORMALLY 0, CHANGES TO 1 FOR REMOTE ALARM

O = NORMALLY 0, CHANGES TO 1 FOR DISTANT MULTIFRAME ALIGNMENT

A number of error conditions can be detected in an incoming PCM data stream. These are:

. loss of input signal

. loss of frame alignment - three/four consecutive frame alignment signals (0011011) have been in error.

. excessive error ratio - Error checking on the frame alignment signal shows an error rate (measure over the course of a few seconds) in excess of 1 in 1000 bits.

. Remote alarm or AIS from upstream PCM equipment.

CCITT recommendation G704 describes a scheme whereby bit 1 of TSO (in both FW and NFW ; frames) is used for the transmission of a CRC covering an 80 frame superframe. This allows error rates smaller than 1 in 1000 to be accurately detected in a more timely manner. This facility is not supported by the majority of PCM equipment currently installed.

5.3.4 T1 24 channel PCM interface

The US standard for primary level (i.e first level of multiplexing) multi channel PCM systems is the 24 channel T1 structure defined in CCITT recommendation G733.

The basic bit rate for the system is 1544kHz. The data is encoded using the HDB3 code described above. Multiples of 193 bits are grouped into a frame. Each frame consists of a single S bit followed by 24 timeslots each of 8 bits. Frames are therefore repeated at an 8kHz rate. Each timeslot provides a data rate of

64Kbit/s. These channels can contain arbitrary data or can carry a single audio signal coded using the *U* law coding scheme.

Alignment to the serial data stream is provided via a four frame structure. Frame 0 contains an S bit set to 1, Frame 2 an S bit set to 0. The S bit within frames 1 and 3 is available for signalling.

An alarm condition is indicated by forcing bit 2 of all 24 timeslots to a logic 1.

5.4 Signalling Over PCM Interfaces

There are three basic mechanisms for signalling over a PCM interface:

- in-band signalling
- Channel associated signalling
- Common channel signalling

These mechanisms are discussed in the subsection below. The descriptions are based on the CEPT PCM system. Whilst similar in concept, the approaches adopted on the T1 system differ in actual implementation.

5.4.1 In - band Signalling

In section 4.1.11 AC15 was described for use in an inter-PBX subscriber environment. It can also be used as an in-band network signalling system where the signals are sent by means of single or MF tone within the timeslot to which the signalling applies. It is usual to cut off the subscriber audio for the duration of the tone. This approach is based on signalling systems in use in Frequency Division Multiplex (FDM) equipment. The system has the advantage that signalling can be transported to intermediate equipment. It allows only a simple repertoire of signals to be sent and has the problem that tones can be simulated by normal timeslot data.

A typical system in use is the AC15 system where a single tone of 2280Hz is used for signalling. The duration of the tone and the current state are used to increase the signalling repertoire available.

5.4.2 Channel Associated Signalling

Channel Associated Signalling (CAS) makes use of TS 16 for the transmission of signalling information. In the CEPT system it provides a signalling repertoire of 15 codes, at a data rate of 500Hz per channel.

PCM frames are grouped into multiples of 16 frames, referred to as multiframe. Multiframe alignment is achieved by means of a multiframe alignment code of 0000 in bits 1 to 4 of TS16 of the first frame of the multiframe. To prevent incorrect multiframe alignment, the code 0000 is prohibited from occurring in these bit positions in TS16 within any other frame. Of the remaining bits of TS16 frame 0, bit 6 is used to signal loss of multiframe alignment to downstream PCM equipment and the remaining 3 bits are spare. The multiframe structure is shown in Figure 4.

Within frame 1, bits 1 to 4 of TS16 contain a signalling code for channel 1 (TS1), and bits 5 to 8 a signalling code for channel 16 (TS17). Subsequent TS 16's contain signalling information for channels 2 and 17, 3 and 18 etc, up to the final frame in the multiframe which contains signalling codes for channels 15 and 30.

In this manner, 15 codes (0001 through 1111) are transmitted every 2ms for each channel. The use made of these 15 codes is dependent on the particular P&T and on the application.
Channel associated signalling is inherently inefficient since it requires fixed bandwidth channels to be allocated for signalling information. It is also limited in the signalling repertoire that it provides. CAS is gradually being superseded by common channel signalling described in the following section.

5.4.3 Common Channel Signalling

Common Channel Signalling (CSS) uses TS16 as a single 64kbit/s message channel. Discrete messages are passed down this channel and each message identifies the timeslots to which it refers. This approach allows more sophisticated error detection to be employed in the transmission of signalling data, allows a large and extensible message set and allocates use of the 64kbit/s channel on an as required basis. A fundamental difference between CAS and CCS is that in CCS the messages mark discrete events, whereas in CAS the signalling data represents current channel state.

In the UK, three types of CCS are employed. Signalling system number 7 is used for signalling between exchanges. In the UK British Telecom (BT) uses its own proprietary Digital Access Signalling System number 2 (DASS2) . This is a system developed for signalling between a subscriber access point and an exchange and enables the future deployment of ISDN. BT have also developed Digital Private Network Signalling System number 1 (DPNSS1) which is used in PBX networks for the extension of PBX facilities throughout the network. All three of the above systems are based on a High Data Link Control (HDLC) protocol.

The HDLC protocol allows arbitrary bit pattern messages to be exchanged. It provides a facility for message delineation by means of a special bit pattern 01111110 termed as a flag. Imitation of flags by message data is prevented by means of zero stuffing, whereby a zero is inserted into the transmitted data stream following five consecutive ones. This zero is detected and discarded by the receiver. A message may be aborted by sending a stream of seven or more ones. When no messages are to be transmitted, continuous flags are sent. The final 16 bits of each message comprise a CRC or Frame Check Sequence (FCS) for the message.

The use of CCS allows a much higher level presentation of signalled data. Thus where in CAS, signalled codes are used to indicate loop make/break for subscriber dialing, this information is communicated in CCS in terms of an already decoded called number. Similarly, call progression tones such as proceed to dial, ringing, engaged and unobtainable are signalled rather than being presented as audio on the traffic highway. This places a greater responsibility on equipment that is attached to PCM highways employing CCS.

5.4.3.1. Digital Access Signalling System No.2 (DASS2)

DASS2 is a signalling system developed for signalling from a subscriber access point to an exchange. It has been developed by BT in the absence of any CCITT recommendations in this area. DASS2 allows multiple channel access facilities suitable for use with multiple channel PCM interfaces. Each traffic channel on the PCM interface has associated with it a Link Access Protocol(LAP). This protocol defines the setting up and maintenance of an end to end communications channel between the signalling devices at either end of the traffic channel. Each LAP operates independently of the LAP's associated with other traffic channels. Messages contain an address field which identifies the traffic channel that they relate to. These messages are interleaved over the physical TS16 link.

The LAP provides a mechanism for acknowledgement of messages by means of a sequence number in each direction of transmission. Control messages sent in one direction must be acknowledged by means of a response message containing the sent sequence number in the other direction. Failure to respond to results in re-transmission of the original message. Repeated failure results in attempts to reset the complete LAP.

At any one time, the LAP may be in one of three states, RESET ATTEMPTED, RESET COMPLETE or INFORMATION TRANSFER. On start-up or as a result of unacknowledged transmissions, the lap enters the RESET ATTEMPTED state. It transmits special message types (SAMBR and UA) in order to establish bidirectional communication . On successful establishment, the LAP enters the RESET COMPLETE state. Signalling information may then be transferred using the LAP.

DASS is based on the International Standards Organisation (ISO)Open Systems Interconnect (OSI) seven layer model which will be described in more detail in Appendix 1. The LAP structure described above implements level 2 of that model. The signalling messages that are actually to be passed across the link sit at level 3 of the OSI model.

DASS messages fall into 2 broad categories, call set-up signalling and maintenance signalling. Typical messages associated with a call set-up are:

- Call initiation request- type of call required, called number, caller's number (if available), supplementary information.

- Incoming call notification - type of call required by caller, caller's number (if available), supplementary information.

- Call accept - acceptance of caller's call.

- Call release request - request to clear down network by caller or called.

- Call release - release of call confirmed by exchange.

In addition to LAP's for traffic channels, a LAP is associated with TS16. This is used exclusively for maintenance messages. Typically this maintenance channel can be used to indicate faults in remote equipment, interrogate such equipment to determine error rates, instigate testing of remote equipment or send configuration information to remote equipment.

5.4.3.2 Digital Private Network Signalling System 1

At the layer 2 level, DPNSS is virtually identical to DASS. At the layer 3 level, DPNSS supports an enhanced message set appropriate to the implementation of PBX facilities such as call divert, group pick-up, abbreviated dialing, callback on busy etc..

This thesis has described so far the market opportunity and the signalling requirements of the Access Network from the subscriber and network perspectives. The following chapter will describe the first of the access systems developed during the course of this project; Rural Access System.

The requirements for signalling to the network have been defined in this chapter. The format of the PCM structure required and methods of conveying subscriber signalling using AC15, Channel Associated Signalling and Common Channel Signalling have been described. Chapter 6 proceeds to define the Rural Access System which was the first of the access systems to be developed.

Chapter 6 Rural Access Systems (RAS)

6.1 Introduction

This chapter focuses on the first implementation of the Subscriber Access Communication System, which was the Rural Access System (RAS). It re-caps the primary market requirements, provides a system level view and identifies the major sub-systems which were employed to realise the design. A typical illustration of a rural network model is provided based on wide ranging data available from the ITU GAS9 study and market research activity undertaken as part of this project. It finally provides a system overview and describes the functional working of each of the RAS sub-systems.

The requirements of rural telecommunication systems have been studied with the objective of developing cost-effective and flexible designs which would be appropriate to those systems at their various stages of growth and, if possible also to distributed urban systems.

In chapter 2 it was shown that the prosperity of developing countries would be materially enhanced by the improvement of their telecommunication systems, particularly in the rural areas which in many cases are at present totally unserved.
The often harsh climatic conditions, long transmission distances, uncertain subscriber traffic demands and frequently inadequate sources of electrical power provided an enormous challenge to

network planners concerned with the provision of flexible telecommunication facilities to these areas.

Communications in such areas can be characterised by factors such as:

- a minimal constraint of existing investment, facilitating revolutionary rather than evolutionary approaches

- long distances, low subscriber density with wide variation in their spatial distribution

- a small initial penetration of the potential user community; which was expected to increase as a direct consequence of prosperity brought by the service

- a primary requirement for simple telephony although eventually demands for more sophisticated services were to be accepted

- a generally fairly hostile environment, physically and electrically

- unsophisticated surroundings and personnel

- a lack of reliable mains power supplies

Political heads in both industrial and developing countries agreed that the provision of reliable, cost effective and modern telecommunication facilities would promote national and social cohesion as well as encouraging the establishment of rural industries. This should then lead on to create employment for the rural communities and so discourage migration of the rural population towards congested urban areas.

Two systems which have found application in rural networks were open wire carrier which was limited in capacity and laborious to expand and point to multipoint time division multi-access radio which while very flexible for small systems was not cost effective at higher capacities due to the need to install completely new radio systems and aerials to serve larger subscriber capacities.

6.2 Requirements for a Rural System

Though requirements varied greatly from area to area, it was possible to make general statements about the desirable features of a rural communications system especially suited to developing countries with initially low subscriber density, but with the possibility of later expansion. These were :

- the system had to be as simple as possible to use, operate and maintain. The reliability of the system was all important. This requirement could be met by the use of managed networks where configuration, fault logging and reporting could be carried out from a few strategically placed control centres. A suitable system should be capable of reconfiguring circuits to maintain services and to remotely locate faults to card level so that repairs could be made by semi or unskilled labour. This allowed the scarce and expensive resources of skilled engineers and repair / test facilities to be located where they were most effective.

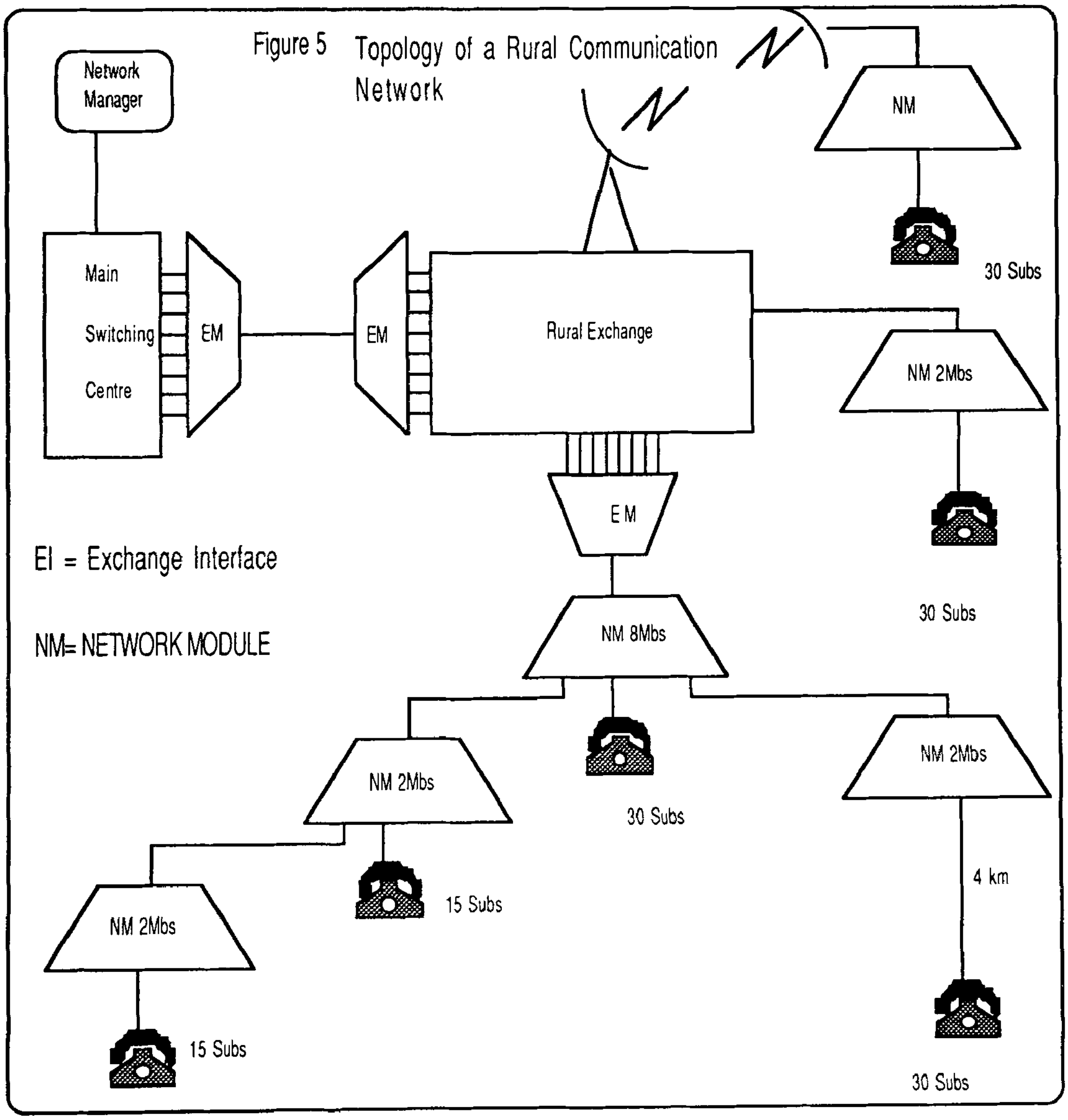
- The equipment chosen should be considered as a total system, where items such as transmission, subscribers and management systems were integrated into a complementary and expandable network. This approach allowed for an easy upgrade to higher bandwidths and bit rate with minimal disruption to existing services. Proper design would also eliminate wastage due to redundancy of old or low capacity equipments through interchange and redeployment to the periphery of the network as the system was upgraded. It should also be possible to change the node configuration to suit the network topology as it evolved and expanded whilst retaining a cohesive and managed network at all stages.

- analogue PSTN and telex services should be supported on initial release but as the network expanded demand for advanced services such as data and even ISDN was expected to increase. The chosen system had to be capable of supporting these services as an upgrade rather than by re-equipping.

- the cost of equipment accommodation and land purchase had also to be considered. The provision of special buildings and facilities for low subscriber densities could make it uneconomic to serve small outlying villages, therefore equipment designed for remote location should be robust and if possible self contained.

6.3 System Topology and Rural Reference Model

Figure 5 displays a rural system topology which uses radio, optical transmission, small rural switches and Network Modules. A combination of all these may be required to produce an effective solution to solve the communication requirement of the rural community depending on terrain, capacity required and future service requirements.



A model was required which was reasonably representative of a typical rural network. This model was based on a real area studied by the ITU and is described below.

6.4 Rural Area Models

To enable the selection of the most suitable communications network which was capable of meeting the rural communities need, it was essential to generate a model of the network under study. The defined model should also enable system planners to compare the cost of alternative implementation plans and to draw conclusions as to which path of development the P&T should proceed along. Information was required regarding geographical locations of the subscribers in the network, traffic densities expected, the origin and destination of traffic and forecast of future growth which together with environmental and logistical data would enable a rural model to be clearly defined. This model had also to be a dynamic representation of the growth in both subscribers and types of telecommunications traffic, to allow networks to be designed with future growth in mind so as not to incur the cost of major modifications to cope with increased requirements during its operational life.

For the purposes of this project, a more general model which could be used as illustrative model was required which represented the types of rural areas which could be encountered in the market place.

It was extremely difficult to evolve such a model due to the wide variations in rural environments throughout the world and also because of the sparse information available in this particular area. Another reason, was the tremendous difference between networks in developing nations in Asia, Africa and developed regions in

Europe and North America, where the telecommunications network was divided into independent areas such as the Trunk , Junction and Local Networks which could be differentiated by factors such as the number of circuits, bandwidth of traffic and distance. These factors dictated the appropriate transmission techniques which were to be used. In developing countries, networks were less likely to have these traditional boundaries and it seemed feasible to look towards the integration of switching and transmission which would in turn bring technologies such as multiplexing, optical transmission of subscriber traffic currently used in the trunk and junction network into the local distribution network serving subscribers.

The ITU and CCITT co-ordinated a case study on a rural area to obtain data and consider the planning specifications to design an economically feasible network solution. This study was undertaken by the General Assembly (GAS) 9 Study Group(1).

6.5 ITU/CCITT GAS 9 Study

A section of the GAS 9 study considered a Rural region and illustrated network planning for rural telecommunications. The areas offered for this rural case study were part of a national study undertaken by the ITU in 1975 which produced the National Plan and strategy for network evolution and modernisation. There was considered to be more information available regarding population distribution, growth forecasts and network objectives then would be typically available for a rural area in a developing country.

A master National Plan for the case study on a particular area covered the following;

- Development priority objectives for the network

- Statistical data e.g quantity of subscriber lines, demographic projections and economic information

- Forecast future demand for telephone services

The area chosen for the rural case study had a land area of 6,600 square kilometres and consisted of an urban town of 100,000 inhabitants, several small towns of about 10,000 people and the remainder of the population was sparsely distributed in many villages of less then a few hundred inhabitants corresponding to 70% of the country's population. The telephone density was .1 line per square kilometre.

The socio-economic data obtained for the area under study confirmed that the rural population had an urgent need in the medium term for one telephone per village. This was considered to be the minimum service necessary to let the population feel that they were an integral part of an integrated community.

The structure of the telephone network in many countries related closely to the administrative organisation of national and regional divisions of the country. In the GAS 9 study the country consisted of regions with their respective capital towns identified as

A_i (1-7). The regions considered in this study were then divided into departments Bj (1-2) which were further subdivided into districts each of which consisted of a chief town identified as C_u (1-10). The lowest administrative level considered in the study were villages identified in the region as V_m (1-1597). Geographic, demographic and economic data inputs were assembled by the study group to provide the case study with the relevant data to enable the model to gain depth and breadth. The geographical information described the physical terrain, weather conditions and general soil conditions prevailing in the area. Locations of major towns with respect to minor town and villages were mapped showing all existing communication links such as roads, railway lines to enable network planners to plan the logistics of installation and maintaining the network. Information regarding production facilities, raw materials available in the area were important inputs which served as an indicator for future requirements as the area developed and grew more prosperous. The economy of the region was also dependant on the types of work the inhabitants performed which would also contribute towards growth forecasts for telecommunication services. Future government and private investments in the region were identified in certain rural areas which would in turn result in greater demand for good telecommunication services. The distribution of the population within the region was approximately 105 inhabitants per square kilometre.The towns in this study area possessed good local power sources while power was virtually non-existent at the villages.

It was important to achieve an integrated system which would allow existing equipment within the network such as analogue switches and transmission to function with the new digital systems proposed. It was the aim of the National Technical Plan to ultimately turn the complete network into a modern digital system. The switching plan described the capacity of local, junction and trunk switching centres; this was required to ensure that sufficient switch capacity was available for rural applications. One of the most difficult areas in the planning of a telephone network was signalling. The majority of subscriber signalling was loop disconnect or magneto signalling. Multi Frequency signalling was expected to be the predominant signalling system to be used by subscriber telephones in the future.

The study predicted that at the initial stage the density of subscribers was approximately 0.1 subscribers/ square kilometre and that this was expected to rise by a factor of 7 over a 25 year period.

6.5.1 Illustrative Rural Model

The GAS 9 case study was reasonably typical of many rural areas in developing countries. It was necessary at this stage of the project to formalise a version of a typical rural network which could then be used in the selection of various system candidates. The model which was evolved from the GAS 9 study which represented countries with a fairly high rural population density of 0.1 subscribers/ square kilometre at the initial point and eventually rising to 0.7 subscribers / square kilometre over a 25 year period. The countries falling into this category were China, India and South America. Countries in certain parts of the African continent and Middle Eastern regions were expected to be less densely populated and were therefore not represented by this illustrative rural reference model.

The model shown in Figure 6 postulates a major city where the exchange is situated . The exchange provides a spur for rural use to a large town located 10 kilometres from the city. The network is then distributed to three villages each of which were sited 15 kilometres form the town. Telephone lines for subscribers in the town were connected directly to the equipment located in the town. The town also served as distribution point for further links to subscribers in three more remote villages.

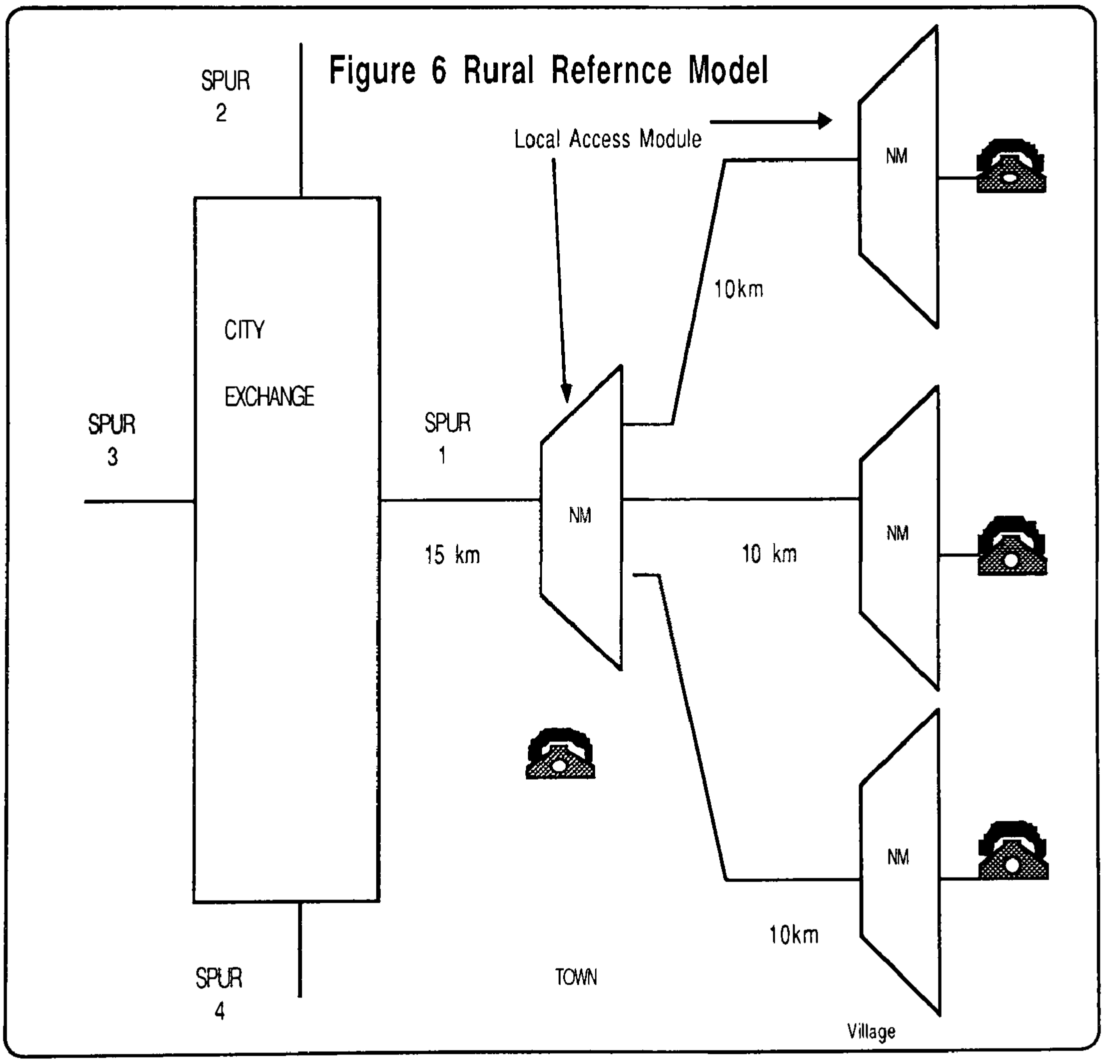
The growth of subscribers in the model was indentified at three points;

-S= Start up (immediately after installation)

-I= Intermediate (10 years after S)

-F= Final growth (25 years after S)

25 years is commonly used by planners as the system life of the equipment. This is being reviewed by P&Ts as new electronic technologies are employed in the local loop and it is expected that 10 years would be considered the system life span in the future.



Growth Stages	Areas	Town	Village
Start Up (S) Yr 0		15	5
Intermediate (I) Yr 10		120	30
Final (F) Yr 25		240	120

Each of the villages were expected to have at the Start Point (S) 5 subscribers, while the corresponding figure for the town was estimated at 15. The number of subscribers for each village was projected to rise to 30 at the Intermediate Point (I) and ultimately to 120 at the Final Point (F);while the corresponding figures for the town were 120 at I and 240 at F.

The services supported at the I Point would primarily be telephony connections with a few data lines for telex and fax. Some of the telephones were expected to be pay phones situated at focal points in the community. It would be reasonable to speculate that after the I point more enhanced services would be required. These were expected to range from uni-directional television for broadcast purposes to two way video links for educational and medical diagnostic use.

6.6 SYSTEM ELEMENTS

Chapter 2 discussed the market and its needs for a rural telecommunications system. This chapter has identified an illustrative model of a rural network with associated growth and service forecasts at three stages in the life of the network. The ability to expand and provide subscriber connections and perhaps even offer sophisticated services such as bi-directional television broadcast to rural subscribers were also identified as future requirements.

After having developed the rural model; it was time to develop a suitable telecommunication system which could be installed in the rural regions. The most popular technologies employed in this area were microwave radio, multi-access radio and small remote switches. The model was employed to undertake teletraffic analysis where the traffic rate per subscriber was assumed to be 0.3 Erlangs. This traffic figure was much higher than the 0.08E which would be used for subscriber traffic in the developed world. The reason for choosing 0.3E was dictated by the fact that there would be a much higher demand from the larger community that was being served by the limited number of telephones.

The traffic analysis went on to specify the processor throughput performance for the various sub-systems which were used to implement the RAS.

The model was also used to undertake a cost comparison analysis with competitive technologies such as small switches and time division Multi-Access Radio. For details of this analysis please refer to Appendicies 2 and 3 of this thesis.

The portfolio of transmission products, optical cables and Flexible Digital Access Multiplexer(FDAM) products within the company were to form the basis of a new system design which would compete with the traditional technologies currently being used in the rural areas. The FDAM will be described in greater detail in Chapter 7. In the following sections of this chapter the FDAM will be treated as a sub-system forming part of larger system within the Access System.

6.7 System Overview

The Rural Access System (RAS) design was capable of serving rural areas via Network Modules (NMs) which could initially provide service to between 5 and 120 subscribers, with the option to grow into a network capable of supporting in excess of 1000 subscribers by use of several interconnected NMs. The NM was designed to work in a large range of climatic conditions using specially designed street distribution cabinets to cope with extremes of temperature, humidity and other atmospheric elements.

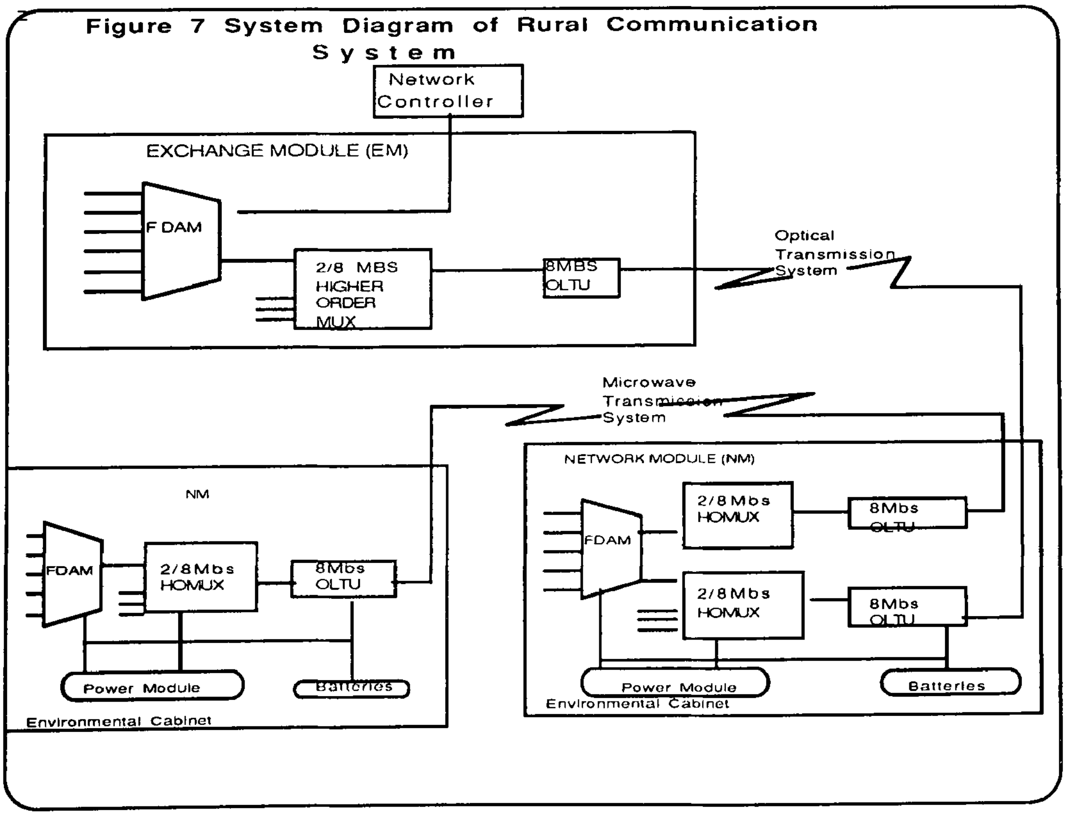
Interconnection between NMs could be accomplished by use of optical fibre cables, specifically designed for rural networks where light weight and small dimensions contribute to low storage, handling and installation costs. Digital microwave and UHF radio systems could also be employed where the terrain and other economic factors make the installation of optical cable inappropriate. The RAS would interface with both analogue and digital switches provided that the switch signalling protocols were adequately defined and accessible.

The key building blocks of the RAS were:

- Exchange Module (EM)
- Network Module(NM)
- Optical and Microwave Transmission Systems
- Network Controller (NC)

Figure 7 illustrates a typical interconnection of these building blocks.

Figure 7 System Diagram of Rural Communication System



6.7.1 System Equipment Description

A Flexible Digital Access Multiplexer (FDAM) was at the core of both the NM and the EM. It was essentially a primary digital multiplex equipment which formed up to 120 timeslots into a number of 2Mbit/s digital streams conforming to the CCITT format.

Timeslot interchange between the 2Mbit/s streams was also possible, under the remote control of the Network Controller, thus if a node had more than one link termination it would act as a drop and insert relay point with full re-routing capabilities. Higher order multiplex cards were used to combine 2Mbit/s streams into 8 and 34.Mbit/s signals.

Being a software based product, it was relatively easy to upgrade to new services by installing the appropriate software into the control card. A range of signalling algorithms were available thereby giving tremendous flexibility in system applications for a wide range of networks. Subscriber configuration was carried out either locally by use of a hand held terminal unit or remotely by the Network Manager. The complete database for the control function was stored within the local control unit thereby ensuring security of information in the event of power loss to the equipment. The NM provided all the necessary interfaces for subscribers, transmission and remote management facilities for a complete node. The network interfaces could be operated at 2Mbit/s or with integral higher order multiplexers at 8 or 34 Mbit/s conforming to CCITT recommendation G.703. This therefore provided an industry standard connection to optical , radio transmission system and if the appropriate signalling protocols were available then connection could also be achieved directly to suitable digital exchanges. The range of analogue interfaces available included earth-calling, loop-calling, direct dialing, E & M and magneto together with interfaces for data equipment , these were described in Chapter 4. Signalling processors converted the various analogue signalling protocols to timeslot 16 signalling within the 2Mbit/s traffic stream. Tone processors were also available which allowed in-band signalling to be achieved where signalling transparency was required across the network.

Remote management for the whole network of multiplexers and line terminating units were supported by an auxiliary maintenance channel which used the spare bits within timeslot 0.

Optical transmission modules operating at bit rates from 2 to 34 Mbit/s were available which could be co-located with complementary second and third order (2-8 & 8- 34 Mbit/s) multiplexers. Alarms from these units as well as the tributary cards were collected by the FDAM processor and were therefore accessible by the Network Controller, enabling all aspects of the system to be remotely monitored, reported and logged.

The near universal use of singlemode optical fibres made this transmission medium more attractive than multi-channel radio as increases in capacity were easily achieved without major investment. The quality of fibre enabled 2,8,34,140 and even 565 Mbit/s systems to use the same fibre types. As optical cards were totally interchangeable, system upgrade was usually achieved by merely changing the optical unit and associated higher order multiplex card. In contrast radio systems upgrades frequently involved total replacement of the multiplex and RF equipments and even changes to the antenna system.

A major aspect in the provisioning of rural services was the replacement to provide buildings and power supplies. Hitherto the establishment of most systems have necessitated the purchase of land for buildings and microwave towers together with associated services such as power, water, drainage and air conditioning. The small size and integrated approach offered by NM based systems enabled the whole equipment for thirty subscribers to be located on a single shelf and for 120 subscribers to be accommodated on four shelves. This allowed the remote equipment to be housed in small street cabinets, not much larger than those used for conventional subscriber distribution.

The Network Module designed for the rural system was based on a Glass Reinforced Plastic (GRP) environmentally controlled street cabinet. The basic unit was capable of accommodating all the equipment and associated power plant to serve up to 120 subscribers together with facilities for dropping 64 kbit/s timeslots and regenerating 2,8 and 34 Mbit/s traffic streams to remote NMs in further rural areas ;see Figure 7. The cabinets were fully equipped with power supply systems and standby batteries capable of maintaining service for up to ten hours in case of failure of the public mains supply. Where public mains electricity supply was not readily available, the low power consumption made solar power a reasonable option.

An external socket was provided for use when prolonged disruption necessitated the use of a portable generator. The temperature inside the cabinet was controlled by the use of both active and passive systems to ensure a safe working environment for the equipment. Alarms associated with power module, environmental control and intruder alert alarm could be extended back to the Network Control centre via the telemetry channel.

The requirement for a very flexible building block for a rural communication system was met by using NMs containing FDAM. When this was combined with low cost , high grade optical fibre links, compact freestanding equipment housings and a powerful network management system; all the key elements were established for a communications system which could be changed and extended as demand and resources permitted. A smooth upgrade path was possible without cost increments which were disproportionate with the increase in size of the user community and without making equipment redundant.

This chapter has developed the rural reference model which was used to illustrate the characteristics of rural networks commonly found in the majority of applications. It also described the Rural Access System at the system level and then progressed to describe each of the sub-systems which made up the overall system. The following chapter shall describe the Flexible Digital Access Multiplexer (FDAM) used to implement both the Network and Exchange Modules (NM, EM).

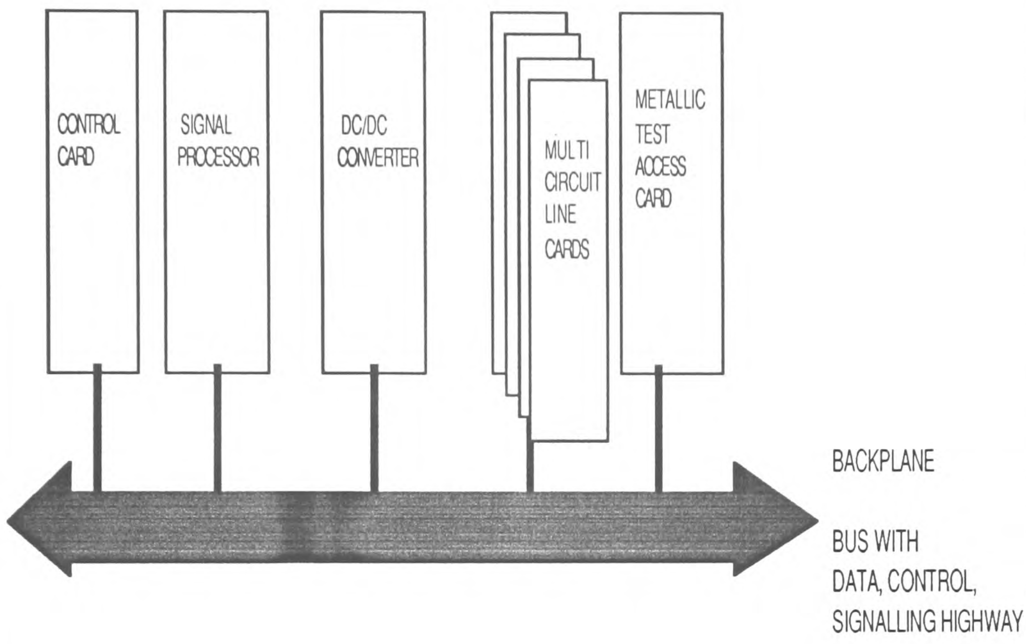
Chapter 7 - The Flexible Digital Access Multiplexer (FDAM)

As a result of the market and technical system requirements described in Chapters 2,3,4,5 and 6 the development group within the company developed further the concept of the Flexible Digital Access Multiplexer to address the market for access systems. The following section provides a design view of the Flexible Digital Access Multiplexer implemented by the design team to meet the needs of the network operator and subscribers of an access system.

7.1. Architecture

The Flexible Digital Access Multiplexer (FDAM) was a rack based equipment developed around a common backplane structure. The core system comprised the rack/backplane and 2 system cards - a DC/DC convertor and a Mux/Control card. A number of conversion processors and standard interfaces - tributaries could be attached to the backplane to equip the FDAM for a particular application. Initial system configuration and in service reconfiguration of the system was supported by a handheld terminal or via the network telemetry bus A typical configuration which illustrates the overall architecture is shown in figure 8.

FigURE 8 FDAM ARCHITECTURE



7.1.1.Core Hardware

The core hardware comprised the following:

- A DC/DC convertor card which generated +12V, -12V, +5V and -5V from a station battery (of typically 48V).
- A Mux/Control card. This card contained the main processor which was responsible for system configuration control. It also contained the logic necessary to drive the backplane busses and a single 2Mb/s PCM interface.

7.1.2Mux/Controller card

The mux/control performed three distinct functions . Firstly, it provided the system processor used for system management and configuration. Secondly, it provided facilities for deriving the backplane master timing. Thirdly, it provided a single bidirectional 2Mb/s PCM interface.

The system processor was based around an 8000 series microprocessor. In addition the processor had a number of peripherals to perform adjunct processing concerned with signalling. Local network telemetry was also supported.

7.1.3 Signalling Card

The signalling card was used only in systems employing channel associated signalling. It formed an intermediate processor between data bound for an external 2Mb/s interface and a tributary channel. One card could handle the processing of upto 32 such connections.

7.1.4 Tone Processor Cards;

Signalling could be performed inband via the use of single or MF tones either on a 2Mb/s interface or on a tributary interface. The 2Mb/s tone processor card detected tones. Its output comprised of blanking during tone and 4 bit signalling codes for input to the 2Mb/s side of a signalling card. In the reverse direction it accepted 4 bit codes from a signalling card and generated tones on the original highway set. Tones were detected and generated using digital techniques. Typically a tone frequency of 2280Hz was used. A single tone processor could handle 32 channels.

7.1.5 Audio Tributary Cards

7.1.5.1 AF8 Audio-only Card

The AF 8 card provided 8 channels of telephone-quality audio, either 2-wire or 4-wire as set up by a slide-switch for each channel. The gain of each channel, in both transmit and receive direction, could also be set remotely. Line protection was provided on the audio lines, up to a maximum voltage of 1kV.

7.1.5.2 Telephone Subscriber Line and Outgoing Signalling Card

The audio side of this tributary was designed to connect to a normal subscriber telephone instrument, or the line side of a PBX. Five lines were provided on the card.

It could support both loop-disconnect and MF4 dialing, and both loop- and earth-calling from PBXs, also any features that involved earthing the B-wire at the subscriber end (e.g. recall, malicious call indication). The card could also be connected to the outgoing side of a junction between exchanges, and supported some of the signalling functions needed between exchanges.

The card applied ringing voltage to the subscriber (produced by a separate ringing voltage generator card), and detected the ring-trip condition (loop condition when subscriber answered). It could also remove feed from one or both lines, required for signalling to some PBXs.

7.1.5.3 Telephone Line Termination and Incoming Signalling Card

This card could simulate five telephone instruments or PBX lines, when connected to exchange lines, including the generation of dial pulses, simulating the output of various types of PBX for signalling purposes (e.g. earth calling), and detecting ringing voltage, line disconnections, line polarity reversal and other signalling conditions.

The card could also be connected to the incoming side of an inter-exchange junction, and provided some of the signalling conditions required.

7.1.5.4DC10 Telephone Exchange Line Interface Card

The DC10 line interface card provided 6 junctions between PBXs, either 2-wire or 4-wire. In the case of 4-wire, the signal wires were connected to phantoms of the two audio pairs, for 2-wire, the audio wires were also used to signal.

7.1.5.5 Magneto Telephone Interface Card

The magneto signalling card both detected and applied ringing voltages (produced by a separate ringing voltage card). This was its only signalling function: its audio side was similar to that of the telephone interface cards, except that it also had to stand a common mode (longitudinal) voltage on the lines of 430 volts RMS AC.

7.1.5.6Metallic Test Access Card(MTA)

The MTA card was interposed between other tributary cards and lines out of the FDAM. It contained relays which, under remote control connected both the line and the tributary line terminals to test buses, which provided access for external test equipment.

7.1.6 Signalling Tributary Cards

7.1.6.1 E and M Signalling Card;

This card provided 16 universal channels of signalling on lines. Each channel could connect earth, or open circuit to each line, or could alternatively detect these conditions. These facilities enabled the card to provide 8 E and M signalling interfaces.

7.1.7 Data Tributary Cards

Two data tributary cards were available for use on the FDAM.

7.1.7.1. G.703 Card

This card had six G.703 interfaces on it. No signalling was incorporated on the card. No line protection was fitted to this card, since it was intended for use within buildings only.

7.1.7.2 X.21 Card

The X.21 card had six interfaces on it. The X.21 card was capable of being remotely configured as either a Data Terminal Equipment(DTE) or Data Communication Equipment (DCE).
In DTE mode, the entire FDAM clock could optionally be derived from one of the clock inputs to this card.

A description of the FDAM which forms an integral part of the access system has been provided in this chapter. The following chapter outlines the generic requirements for a Network Controller used to operate, administer and maintain an access system.

Chapter 8 - Network Controller (NC)

The previous chapter focused on the FDAM architecture and system components implemented by the development team. In an access application the number of FDAMs can range from ten as shown by the Heathrow Airport network described in Chapter 3 to several thousand in a large Business Access System such as Flexible Access Services (BAS) implemented in the City of London to serve the communication needs of the stock brokers and dealers during the " BIG BANG" period in the City of London during 1986.

It was clear that to effectively manage and control an access network, it was important to have remote network management capabilities. This would allow systems to be operated and administered with a small workforce who could be based in a central network management location. The requirements for such a system shall be identified in this chapter. These requirements were provided to the Network Management development team who translated the requirements into a working system to be used for Access System applications.

8.1 Network Controller Requirements

The Network Controller had to provide the following functions for use in an Access Network:

- Initialisation and Configuration
- Maintenance
- Man Machine Interface

- Background Audit / Integrity Checking
- Network Control Self Management

The above functions were required to enable the Network Operator to carry out operation, maintenance and administration of the system remotely without having to resort to site visits. This was essential if operating and maintenance costs of this type of network was to be considerably lower than the traditional copper based systems.

8.1.1 Initialisation and Configuration of Services

This function allowed the building of an Access System by establishing the existence of Network Module (NM) together with its associated FDAMs and Exchange Modules (EM). This feature would also be responsible for setting up the communications path between the various network elements such as the NMs and EMs to the Network Controller. It would also have to provide the ability to uniquely identify and address each network element by using the appropriate coding scheme. Attributes such as alarm thresholds on the network transmission interfaces of the network elements and parameters such as line gains and physical circuit to PCM timeslot connection would also be carried out by this feature. On a command from the Network Controller, network elements had to be readily added or removed from the system configuration. It was also a requirement that this function provide the facility to remotely interrogate the network elements and determine its physical state with regard to cards plugged in and operational state in terms of active circuits connected via the Network Module to the Access Network.

8.1.2. Maintenance

This function would be responsible for recognising and displaying alarms to the operator at the Network Controller. The operator would also require the ability to log alarms into an archive with associated date and time stamp information. Common equipment, line card and loop diagnosis were also to be supported by this feature. This would allow the operator to remotely diagnose faults and despatch the correct replacement units to site. The ability to archive faults into a log would enable the maintenance staff to conduct analysis of faults occurring in the network with other associated events such as tropical lighting storms or perhaps civil construction work occurring near the telecommunications equipment which may have caused the fault.

8.1.3.Man Machine Interface(MMI)

The objective of the MMI was to present information on the Network Controller in such a manner that enabled the network operator to interact and use the system with ease. Two types of MMI implementation could be used, these were either Forms based or Icon type MMI. The Forms based MMI presented information to the user as conventional forms which the operator would have used manually to record or order changes.

The Forms based MMI would guide the operator to fill in the appropriate sections in order to proceed with a task. An Icon type MMI would present information in a graphics format which was closely aligned to the equipment or type of task that was being implemented. Examples of this would be presenting the operator with pictures of the wiring block with subscriber names annotated on it or presenting a picture of the equipment with all the various units residing on it.

8.1.4. Background Audit / Integrity Checking

The function of this feature would be to instigate a range of background test procedures which would ensure that all the network elements and the Network Controller are sane and operating correctly. This would normally be achieved by monitoring watch-dog timers and checksums originating from the NMs, EMs and NC.

8.1.5. Network Controller Self Management

This feature would be required to provide support facilities to enable software and databases to be loaded, copied and deleted when required including logon procedures to prevent unauthorized access and security.

8.1.6 Network Control Communications Facilities

Network control would be carried out by means of the transmission of management messages over Network Telemetry (NT) channels within the network. The communication mechanism to be used was telemetry over the 2Mb/s PCM link by means of a spare bit within the Not Framed Word ofTS0 which provided (4Kb/s) for data transmission.

8.2 Network Controller Implementation

The development team accepted these requirements as identifying the prime needs for the control and management of an Access System. They proceeded to develop a network controller based on intelligent workstations. Configurations were available with single manager workstation or as multiple workstations connected via Ethernet with a central fileserver.

For large networks, the basic limitations of the FDAMs networking capabilities were overcome by breaking the network up into a number of smaller telemetry networks. Each network was controlled by a 'message switch'. The message switch was responsible for passing data between the network manager and its connected FDAM network and performed routine tasks such as alarm polling automatically.

A list of technical requirements has been defined here for a Network Controller to be used in access systems. The following chapter shall describe the second application of an access system to provide advanced, flexible services to the urban business centres.

Chapter 9 Business Access System (BAS)

In Chapter 2 it was stated that the access market was segmented into two groups:

- Rural Access System

- Business Access System

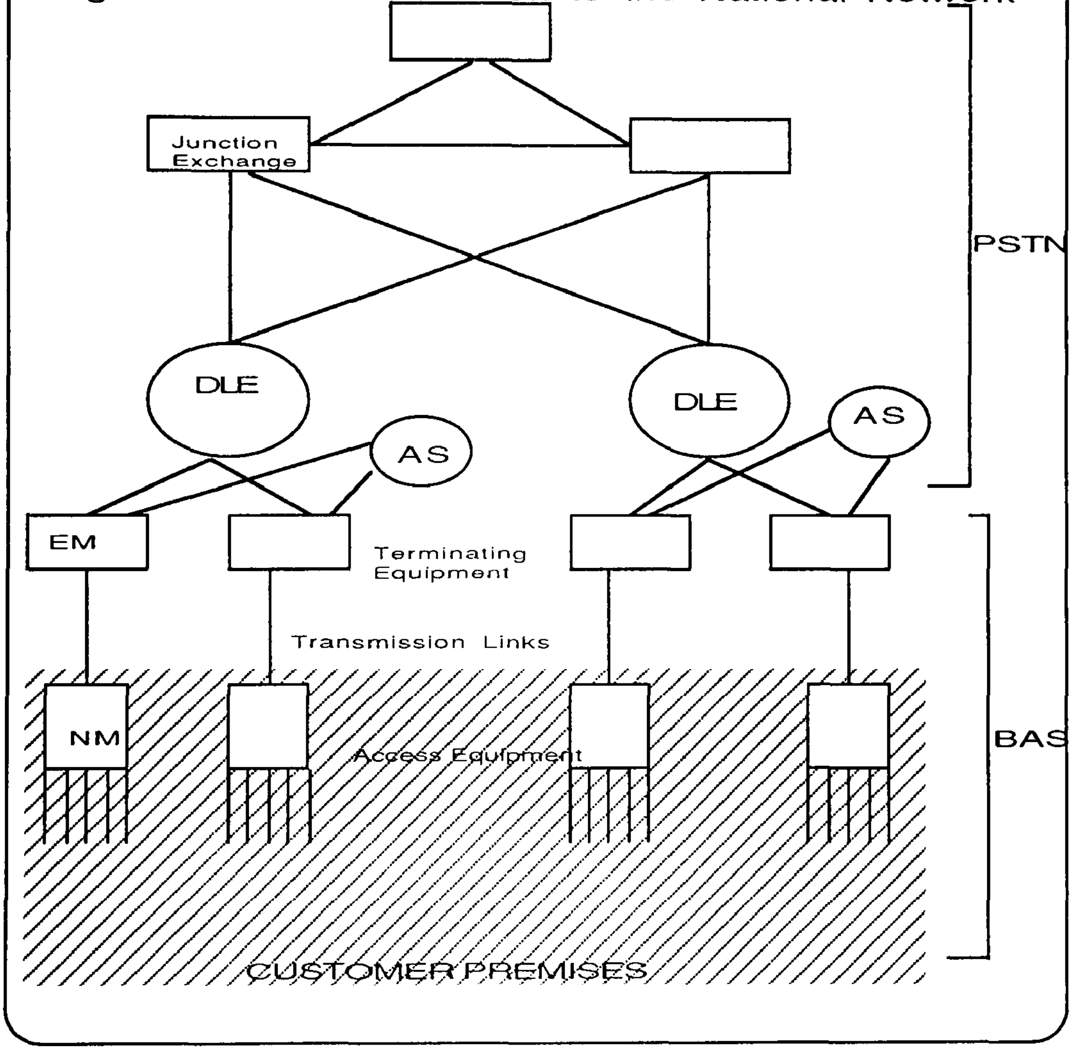
Chapter 6 discussed the Rural Access System interms of its requirements, topology and system elements. This system was primarily aimed at the first time provisioning of telecommunications services in a green field environment where services were virtually non existent. The Business Access System described in this chapter utilised many of the concepts developed for the rural application but was aimed specifically at the needs of the urban industrialised business centres of the developed world.

This section will describe the system implementation by highlighting topology, network side interfaces and subscriber side functional interfaces together with associated signalling.

9.1 Introduction to BAS

The Business Access System provided customers of a network with access to the services offered by that network. Access in this context implies a metallic termination, suitable for direct connection to customers' equipment, which formed the local end of a circuit through to the lowest level of the network infrastructure (for example, the local exchange). One particular implementation of BAS was Flexible Access Systems(FAS) for British Telecom in the UK. The deployment of BAS in relation to the National Network is shown in Figure 9 below.

Figure 9 BAS in Relation to the National Network



DLE=Digital Local Exchange

AS = Access Switch

EM=Exchange Module

NM=Network Module

In terms of network structure, The Business Access System (BAS) can be thought of as being an additional layer interposed between the Local Exchange Level and the customers' equipment (see figure 9. An essential feature of BAS was the deployment of access equipment known as Network Modules (NMs) on the customers' premises. The access equipment provided access (as defined earlier) to:

- normal circuit-switched telephony services (PSTN), by providing onward connection of circuits to the Digital Local Exchange
- to a variety of unswitched services, by providing onward connection of circuits to an Access Switch (AS), which had the ability to set up semi-permanent connections of customer circuits to services other than PSTN.

The access equipment was provided with a high-capacity link (either 120 or 480 circuits) to 'terminating equipment'. From there, the customers' circuits were provided with onward connection to either the DLE or the AS, according to the type of service being provided on each circuit.

The essential principles of BAS as an access system were :

- Based upon the deployment of 'access equipment' at the customers' premises, which provided the customer with a unified point of access to all types of service, switched or unswitched, voice or data.

- Based upon the use of optical fibre transmission to provide services to the customers' premises.

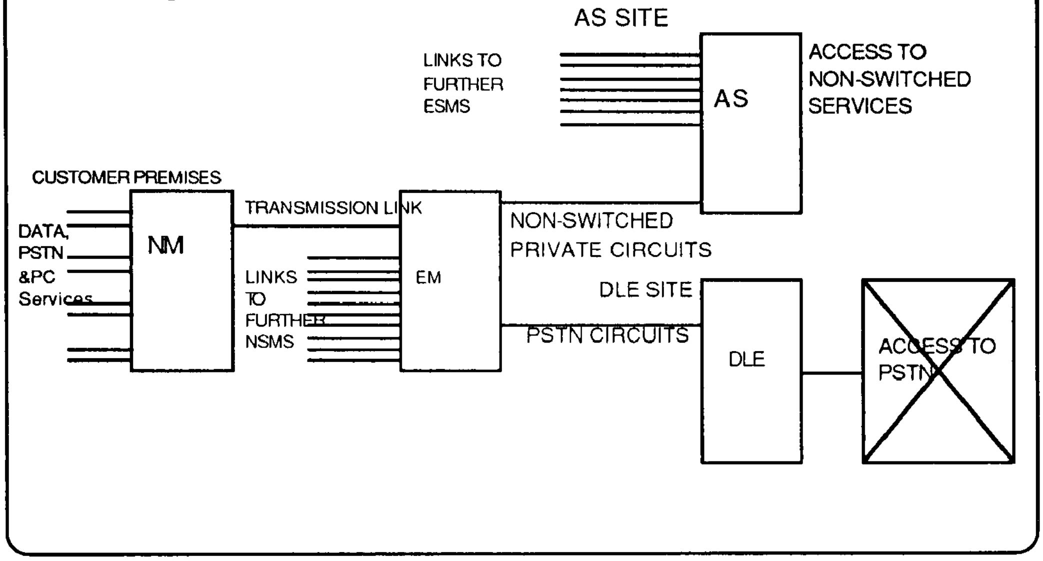
- All the main elements of BAS, including the access equipment, the transmission links, and the AS, were remotely managed and configured from a number of central management facilities.

- Provided a wide range of voice and data services at the access equipment. Since the access equipment and the AS were software-configured, the number and types of services could be rapidly reconfigured to accommodate the changing requirements of the business customers.

9.2 The traffic handling structure of BAS

The main traffic-handling elements of BAS, shown in figure 10 were:

Figure 10 BAS ELEMENTS



9.2.1 The Network Module (NM):

This was the 'access equipment'. It provided the customer with a number of two- and four-wire interfaces, suitable for connection to the customers' terminating equipment (telephones, PABXs, or industry-standard data terminating equipment).

9.2.2 Transmission Link:

Each NM was served by an optical-fibre transmission link, duplicated for security, and operating at either 8 Mb/s(capable of handling up to 120 customer circuits) or 34Mbit/s(up to 480 customer circuits). This link carried all the traffic and any signalling associated with the customers' circuits, whatever type of service (or mix of types) was being provided by the NM.

9.2.3 Exchange Module (EM):

This was the 'terminating equipment'. The EM terminated the optical transmission link at the exchange end, and extended the circuits provided for the customer, to the Digital Local Exchange (in the case of 'switched circuits' - PSTN) or the Access Switch (for 'non-switched' circuits - private circuits for voice or data).

9.2.4 Digital Local Exchange (DLE):

The DLE provided connection for the switched circuits to local terminations or to the trunk network, according to the signalling information associated with each circuit.

9.2.5 The Access Switch(AS):

The AS was based on similar equipment to the Digital Local Exchange equipment, and provided semi-permanent connections for private circuits. By way of the AS, circuits provided by an NM could be connected to other NMs within the BAS network or, via leased lines, to remote locations. The AS could be thought of as a Digital Exchange without the ability to interpret customer line or network signalling; instead, connections were set up under the control of the network operating authority, in response to customer requests for services.

9.3 Customer Services

The services offered to customers by the Business Access System covered a wide range of voice and data telecommunications services:

- Telephony services over the Public Switched Telephone Network: direct exchange lines, or PBX exchange lines with or without DDI (Direct Dial-In).
- Private telephony circuits to link PABXs, or for 'remote extension' facilities.
- Private data circuits at a variety of data rates, offered over industry-standard interfaces.

9.4 Signalling

Signalling between the NM and the DLE, for circuit-switched telephony circuits, used a subset of the DASS2(Digital Access Signalling System 2) message-based signalling system. The messages associated with this signalling system were assigned separate 64kbit/s channels within the transmission links between the NMs and the DLE. The NM was responsible for providing translation between the DASS2 messages, and the customer line signalling protocol, such as loop/disconnect or DTMF.

Services supported by the DASS2 subset used included:

- Basic call set-up.
- Use of Recall (earth or timed break) in call, followed by digits or use of the telephone "*" and "#" pushbuttons to initiate supplementary services outside calls.

The support of the"*" and "#" key sequences by the DASS2 subset did not automatically imply that the corresponding services were available: this relied upon the DLE supporting such services.

This chapter described the Business Access System application which evolved from the work undertaken for Rural Access Systems. The next chapter examines areas of the access system which should be modified and improved in future developments undertaken to address similar access applications.

Chapter 10 Improvments and Future Trends for Access Systems

10.0 Introduction

This chapter undetrtakes a critical review of the sub-systems which make up the overall Access System. The deficiencies and limitations of the existing systems are identified to enable system designers of future access systems to be aware of some of the technical problems which were encountered in this project.

Recommendations are also made in this chapter for improvements which should be considered to enable the system to offer increased flexibility and functionality in future applications.

10.1 Improvements

10.1.1 Transmission Interface

NMs and EMs developed for both the Rural and Business Access Systems were designed to operate with either 8 or 34 MBit/s plesiochronous network interfaces. This transmission structure required the system to demultiplex the high transmission rates of 8 and 34 MBit/s down to 2 MBit/s and ultimately to 64 Kbit/s channels in order to obtain access to the subscriber circuits. The complexity and cost associated with the demultiplexing circuit could be removed by developing synchronous transmission network interfaces which would allow access to any desired multiple of 64kbit/s of bandwidth to be extracted from a network interface. the benefits provided by this change are:

- Increase transmission rates to 565 Mbit/s or 1Gbit/s could be used to provide a wide range of new subscriber services such as video phone and dial up video or music entertainment facilities .

- Ring based topologies could be implemented which offer high transmission security and resilience by offering alternative routing capabilities within the network.

10.1.2 Diagnostics and Self Checking

Both of the network elements, NM and EM should be designed with local self management which would enable the units to detect changes in operational status of equipment and request for software download either on startup or in the event of software faults. This would also eliminate the need for site visits by maintenance personnel to change EPROMS and ROMS which contain the operational software.

10.1.3 Subscribe Line Interfaces

The number of line cards required to support the various subscriber services should be reduced, with ideally one line card to serve all the subscriber interface requirements. The line card should also incorporate line card testing, loop diagnosis and have protection built in to withstand induced lightning and mains cross hazardous voltages or currents.

10.1.4 Duplicated Control

To provide improved network resilience and security all control functions within an access network should be duplicated. This would also allow new software to be downloaded to the NMs and EMs with minimum disruption to service by loading the new software to the spare control section.

10.1.5 Cabling Interfaces

All line card and control card cable interfaces should be located away from the cards and placed on a connectorised bulkhead. This will ensure that there is clear access to all cards in the system and enable quick installation and removal of units for maintenance.

10.2 Network Control Improvements.

The use of spare bits in TSO meant that the time required to configure or interrogate the network elements was unacceptably long. The system employed had the following effects which also contributed to the long communication times.

- Telemetry data rate of 4K bit/s was too low

- The messages were transmitted through in chain of units.

- No provision was made within the message protocol for interleaved transmission to enable a large set of instructions or responses to be carried.

Improvements to future Network Controllers should enable enhanced alarm surveillance, automatic reporting, and diagnostics. A much larger telemetry channel, ideally 64 Kbit/s should be employed to communicate with the network elements. A bi-directional communications path should be implemented to allow the Network Controller and network elements (NMs, EMs) to replay information between them. A message based protocol which Remote Operation(RO) instructions should be utilized. These ROs should be capable of being relayed to their destination independent of the type of link that was used to transport them. This would then allow the RO to be conveyed by:

- Packet Switched networks

- Local Area Networks

- Proprietary non-traffic carrying channels such as the overhead capacity in an optical transmission system created by operating the optical transmission system at a higher data rate than is required to transport the customer traffic. The channel should also be used to download software to the NMs and EMs in the access system.

Specific areas of the access system have been identified in this chapter which should be improved in any future implementations of this type of system. The next chapter provides the conclusion by summing up the progress achieved at the end of the scheme.

Chapter 11 Conclusion

The primary objectives set at the outset of this project was to undertake an investigation of the technologies available or capable of being developed to address the needs of the telecommunication operator and end-user. This led to the identification of opportunities to develop suitable systems based on optical fibre transmission to develop a larger market share for optical fibre cables sales, and thereby achieve the business objective stated for the project.

The initial part of the project was focussed on the market place to develop a detailed view of the market requirements, application segments and deployment potential for access systems. This research revealed that there were two specific market segments for an Access System. These were Rural Access Systems for the provisioning of first time communication facilities in the developing countries of the world and the second segment was for Business Access Systems for advanced flexible facilities in the industrialised countries of the world.

After establishing the market data, the project focus was directed towards defining the technical requirements of the access communication system, which would be used by the design teams as the basis for development activities. The technical requirements were identified for the subscriber signalling interfaces, network signalling interfaces, system topology and network control. Each of these technical areas were identified as a result of studies undertaken to evaluate the specific features required to address the majority of applications in the market place.

Chapter 7 of the thesis described the Flexible Digital Access Multiplexer which formed part of the core of the Access System by providing the vehicle for optical fibre deployment, signal processing and subscriber interfaces to a wide variety of terminals. The Network Controller required to remotely operate, administer and maintain the network was also defined as part of this project.

The technical solution specified to resolve the problem of rural communications was also used to serve the needs of the business community in the industrialised nations of the world. The Business Access System used many of the elements identified for the latter application.

Both of the access systems have been implemented in real applications to serve the communication needs of several P&T organisations. Rural Access Systems were deployed in Jordan, as part of first time service provisioning to subscribers in the north of the country. The system was also seriously evaluated by the Omani, Solomon Islands, Chinese and Indian P&Ts but due to resource issues within the company these project were not completed. The focus of the team switched to the Business Access System during late 1986 where several Flexible Access systems(FAS) were deployed for British Telecom in the UK. The market for access systems still continues to exist with the emphasis being taken up by larger telecommunications organisations around the world. This project has shown the critical need to closely couple technology with the market place in order to successfully develop access systems which are helping to push telecommunication networks into the next century.

Appendix 1 OSI Reference Model-General Explanation

A.1 Introduction

In Chapter 3 it was stated that DASS2 network signalling was based on ISO's OSI model; this appendix illustrates the OSI concept in more detail for the readers information.

The International Organisation for Standardisation (ISO) has been working since 1976 to produce standards to promote the free interworking of information systems via communications known as Open Systems Interconnection (OSI) . The term OSI qualifies standards for the exchange of information among systems that are "open" to one another for this purpose by virtue of their mutual use of the applicable standards. "Openness" does not imply any particular systems implementation, technology or interconnection means, but rather refers to the mutual recognition and support of the applicable standards.

It was realised that to successfully tackle such a wide-ranging area of standardisation a structured breakdown of the task was required. This has been provided by defining a Reference Model for OSI which is structured into 7 layers namely the application, presentation, session, transport, network, data link and physical layers. This reference model provides a conceptual and functional framework which allows international teams of experts to work productively and independently on developing standards for each layer. The activities of ISO have since consisted of a number of parallel activities to define the reference model, which has now been approved as a Draft International Standard, and to develop standards for the individual layers.

More recently, the CCITT has decided to adopt a Reference Model for Public Data Network Applications and there is collaboration between ISO and CCITT to ensure that the two models are consistent.

A.2 Scope

The ISO version of the OSI Reference Model is applicable to all user to user communicating systems which are 'open' whether using public or private communications facilities.

The CCITT version of the OSI Reference Model is restricted in application to user to user communicating systems which communicate over a public data network, either alone or in tandem with one or more compatible networks. The CCITT networks included are leased lines, circuit switching and packet switching and the use of the PSTN and Telex Network for data are also considered. The user in this context may include internal Administration users (e.g. for communicating operations and maintenance information).

A.3 Principles of Layering

Partitioning is a common method for developing structured solutions to complex problems and is the technique used in the Reference Model.
According to this technique, each system is viewed as being logically composed of a hierarchy of subsystems containing one or more entities (functional units - CITT). Subsystems of the same rank collectively form a layer of the OSI Reference Model.

Except for the highest layer, each layer provides a layer service to entities in the layer above. Each layer uses the services of the next lower layer, plus its own functions, to create new services which are made available to the next higher layer. The operation of a layer, that is the communication between entities within a layer, is governed by a set of protocols specific to the layer, known as a layer or peer protocol.

a. Layer Service
b. Layer Interface
c. Peer or Layer Protocol

A.3 The 7-Layer Model

The general principles of a layered architecture have been described above and to apply these principles to the OSI environment, a number of criteria may be used in performing the partitioning of the system as follows :

1. The first criterion relates to the number of partitions defined. There should be a sufficient number of partitions such that each partition of a solution can be easily comprehended. At the same time, there should not be so many partitions that the task of describing and engineering the system will be difficult.

2. Boundaries should be selected such that similar functions are located in the same partition and unrelated functions are in different partitions. This usually minimises the number of interactions across the boundary and results in simpler boundary descriptions.

3. Boundaries should be selected to permit flexibility in a structured manner. A partition should be defined where alternate technologies exist or are foreseen. This permits these technologies to be introduced without affecting other partitions. A boundary should be selected to coincide with present standards or procedures such that existing equipment is not made obsolete and an evolutionary plan can be developed. The boundaries should be selected such that the functions performed by a partition can effectively contribute to the solution by minimising redundancy, and such that optional functions can be inserted or by-passed, thus ensuring that the total solution is cost effective yet still structured.

The application of the criteria described above has led to the identification of seven layers, which are briefly described below.

A.3.1 Physical Layer

The physical layer provides mechanical, electrical, functional and procedural characteristics to activate, maintain and deactivate physical connections for bit transmission between data-link-entities. A data circuit is defined as a communication path in the physical media between two systems together with the facilities necessary in the physical layer for the transmission of bits onto it. A physical connection may be provided by the interconnection of data circuits by the use of a physical layer relay as illustrated below.

A physical connection may be point-to-point and allow duplex or half duplex transmission of bit streams.

A.3.2 Data Link Layer

The data link layer allows exchange of data link data units over a data link connection. The size of the data link units may be limited by the relationship between physical connection error rate and the error detection capability. The functions of the data link layer include:

- data link end-point identities if required for multi-point
- maintenance of sequence integrity
- data link connection establishment and release

- data link connection splitting onto several physical connections
- data unit delineation (e.g. frame detection)
- sequence control
- error detection
- error recovery and reporting to network layer unrecoverable errors
- flow control
- normal and expedited data
- path purging procedures (reset)

A.3.3 Transport Layer

The transport layer provides transparent transfer of data in a reliable and cost effective manner, optimising the use of resources according to the type and character of the communication. The transport layer enhances the quality of the network service (e.g. cost reduction by multiplexing, reliability by error recovery, re-establishment of virtual circuits after failure, etc.). Specific enhancements of the quality of service may be achieved by means of optional functions within the transport layer according to the quality of service required. The functions of the transport layer may include:

- mapping transport address onto network address
- transport connection establishment/termination
- quality/class of service selection
- multiplexing transport connections onto network connections
- end-to-end sequence control, flow control, error detection and recovery

A.3.4 Session Layer

The session layer provides the means necessary for cooperating presentation entities to organise and synchronise their dialogue and manage their data exchange. The functions of the session Layer include:

- session connection establishment/termination
- quarantine service
- dialogue control
    - one way
    - two way alternate
    - two way simultaneous
    - session connection synchronisataion

A.3.5 Presentation Layer

The purpose of the presentation layer is to represent information to communicating application entities in a way that preserves meaning while resolving syntax differences. The presentation layer adds the following facilities:

- data syntax transformation
- data formatting
- transformation of presentation image definition
- syntax selection
- selection of presentation image definition

Examples of presentation layer services are:

- code translation
- data compression

- data encryption
- command translation (virtual terminals)
- presentation format (screen, page, line)
- data structure

A.3.6 Application Layer

As the highest layer in the Reference Model the application layer provides a means for the application process to access the OSI environment. All specifiable parameters of each OSI environment via the application layer. The layer provides all services directly usable by application processes. In addition to information transfer such services may include:

- identification of communication partners (by name, address, definite description, or generic description)
- determination of availability of communicating partners
- establishment of authority to communicate
- agreement on privacy mechanisms
- authentication
- determination of cost allocation
- resource adequacy determination
- quality of service determination
- selection of dialogue discipline
- identification of constraints on data syntax

A.4 Application of the Reference Model to Public Data Networks

A public switched data network when providing a basic network service such as X21 or X25 is concerned only with the lower 3 layers of the model namely the physical, data link and network layers. The network is then transparent to the higher layers of the model. In the case of X25 levels1-3 of the X25 recommendation broadly correspond to the lower 3 layers of the model. In the case of X21 only a minimal link and network layer protocol is defined sufficient for communicating network signalling and during the data phase of a call the network acts purely as a physical relay and becomes transparent to all the layers except the physical layer as shown in the figure.

The higher layers which are not determined by the network may be defined by:

- users
- manufacturers protocols (e.g. IBM's SNA)
- international standards (e.g. ISO standards)
- CCITT standards for specific services (e.g. Teletex, Videotext)

The Administration may also be involved in handling some or all of the higher layers when it provides services in excess of the basic network service such as protocol conversion or message handling services. Examples of such services which may be provided either in public networks or additional modules such as gateways or service units include:

- PAD functions as defined in X25, X28, X29
- Telex <--> Teletex conversion
- Teletex <--> Video conversion
- Message store and forward

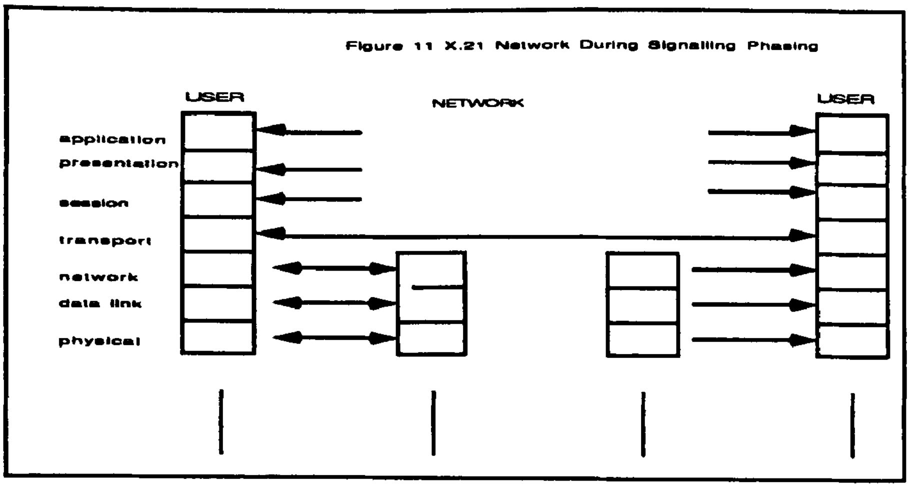


Figure 11 X.21 Network During Signalling Phasing
USER
NETWORK
USER
application
presentation
session
transport
network
data link
physical

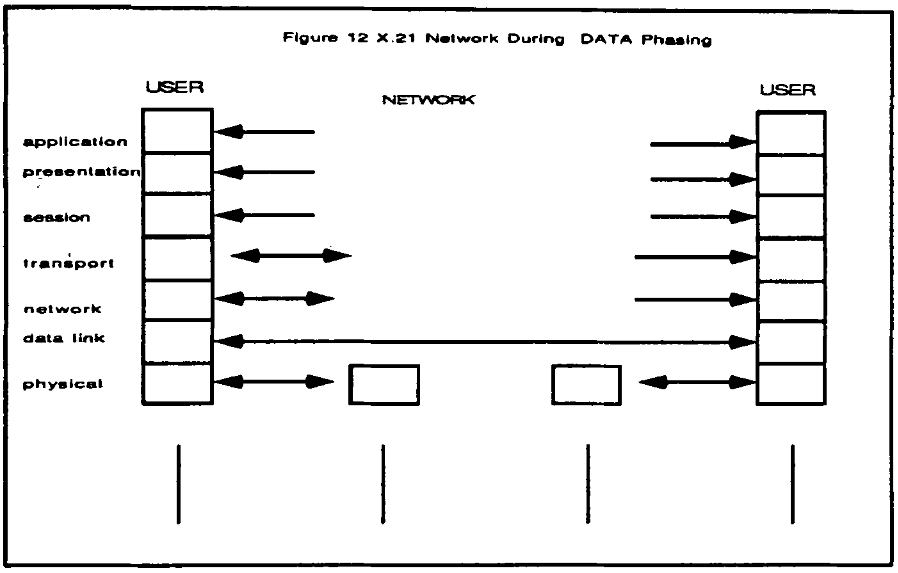


Figure 12 X.21 Network During DATA Phasing
USER
NETWORK
USER
application
presentation
session
transport
network
data link
physical

Appendix 2 Flexible Rural Systems

1988, Conference Proceedings on Rural Telecommunicati
23-25 May 1988, IEE.

FLEXIBLE RURAL SYSTEMS

Pereira, T.J., Steven, D.L., Field, C.

STC Telecommunications, UK

INTRODUCTION

The requirements of rural telecommunication systems have been studied with the objective of developing cost-effective and flexible designs which would be appropriate to those systems at their various stages of growth and, if possible also to distributed urban systems.

FLEXIBLE RURAL COMMUNICATIONS

It is internationally recognised that the prosperity of developing countries would be materially enhanced by the improvement of their telecommunication systems, particularly in their rural areas which in many cases are at present totally unserved. The International Telecommunications Union set up the Independent Commission of Worldwide Telecommunication Development, commonly referred to as the 'Maitland Commission', to study the problems of the developing world and to produce a strategic plan to improve telecommunications and in many cases provide a first time service to the rural areas of the developing world.

The often harsh climatic conditions, long transmission distances, uncertain subscriber traffic demands and frequently inadequate sources of electrical power provide an enormous challenge to network planners concerned with the provision of flexible telecommunication facilities to these areas.

Communications in such areas are characterised by factors such as:

- a minimal constraint of existing investment, facilitating revolutionary rather than evolutionary approaches
- long distances, low subscriber density, with wide variation in their spatial distribution
- a small initial penetration of the potential user community; this is expected to increase as a direct consequence of prosperity brought by the service
- a primary requirement for simple telephony although eventually demands for more sophisticated services are to be expected
- a generally fairly hostile environment, physically and electrically
- unsophisticated surroundings and personnel
- a lack of reliable mains power supplies

Politicians in both industrial and developing countries agree that the provision of reliable, cost effective and modern telecommunication facilities will promote national and social cohesion as well as encouraging the establishment of rural industries. This should create employment for the rural communities and so discourage migration of the rural population towards congested urban areas.

Two systems which have found application in rural networks are open wire carrier which is limited in capacity and laborious to expand and point to multipoint time division multi-access radio which while very flexible for small systems is not cost effective at higher capacities.

REQUIREMENTS FOR A RURAL SYSTEM

Though requirements will vary greatly from area to area, it is possible to make general statements about the desirable features of a rural telecommunications system especially suited to developing countries with initially low subscriber density, but with the possibility of later expansion. These are:

- the system must be as simple as possible to use, operate and maintain. The reliability of the system is all important. This requirement can be met by the use of managed networks where configuration, fault logging and reporting can be carried out from a few strategically placed control centres. A suitable system should be capable of reconfiguring circuits to maintain sevices and to remotely locate faults to card level so that repairs can be made by semi or unskilled labour. This allows the scarce and expensive resources of skilled engineers and repair/test facilities to be located where they are most effective.
- the equipment chosen should be considered as a total system, where items such as the transmission, subscribers and management systems are integrated into a complementary and expandable network. This approach allows for an easy up-grade to higher bandwidths and bit rates with minimal disruption to existing services. Proper design also eliminates wastage due to redundancy of old or low capacity equipments through interchange and redeployment to the periphery of the network as the system is upgraded. It should also be possible to change the node configuration to suit the network topology as it evolves and expands whilst retaining a cohesive and managed network at all stages.
- analogue PSTN and telex services should be supported on initial release but as the networks expand demand for advanced services such as data and even ISDN

will increase. The chosen system must be capable of supporting these services as an upgrade rather than by re-equipping.

- the cost of equipment accommodation and land purchase must also be considered. The provision of special buildings and facilities for low subscriber densities can make it uneconomic to serve small outlying villages, therefore equipments designed for remote location should be robust and if possible self contained.

SYSTEM TOPOLOGY AND RURAL REFERENCE MODEL

Figure 1 displays a rural system topology which uses radio, optical transmission, small rural switches and STC's Local Access Modules. A combination of all these may be required to produce a cost effective solution to solve the communication requirement of the rural community.

A model has been developed which is reasonably representative of a typical rural network, Figure 2. This model is based on a real area studied by the ITU.

The model postulates a 'city' in which the exchange serving the rural network is situated, perhaps being co-located with one or other of the exchanges which serve the city itself. Four spurs run from the exchange to four 'towns' which are on average 15km away, which together with their surrounding areas, have not hitherto had a communications service. The 'towns' serve a certain number of subscribers directly, as well as providing a distribution point for the links to the clusters of subscribers at each of three 'villages' at an average distance of 10km.

The number of subscribers served by this spur are given for three stages of development:

Stage A	immediately following first installation (Yr. 0)
Stage B	at an intermediate stage (Yr. 10)
Stage C	complete (Yr. 25)

The subscriber densities at both towns and villages are indicated in Figure 2.

Three alternative designs were modelled which could serve the communication needs of this rural configuration:

1. A local switching system using conventional remote switching units located in the town which serve village subscribers using line extenders.

2. A time division multi-access radio system with nodes in each town serving the village communities

3. A flexible multiplex system of the type illustrated in Figure 1.

The relative cost of capital equipment and installation of the three systems for various subscriber densities served by each town node is shown in Figure 3. It can be seen that system 2 is cost effective for small user communities but has a high cost of expansion and system 3 offers the best long term solution where subscriber numbers are likely to exceed a hundred. The designs are based on 10-15km internode distances. The possible use of different transmission bearer systems in System 3 is discussed in Holden et al (1).

The above analysis includes all capital and installation costs for the three systems but does not include any operational costs. System 3 will in fact offer the lowest cost of operation due to the minimum use of outside plant and the application of network management.

SYSTEM OVERVIEW

The Rural Communication System (RCS) design is capable of serving rural areas via Local Access Modules (LAM) which can initially provide service to between 5 and 120 subscribers, with the option to grow into a network capable of supporting in excess of 1000 subs by use of several interconnected LAMs. (see Figure 4) The LAM is designed to work in a large range of climatic conditions using specially designed street distribution cabinets to cope with extremes of temperature, humidity and other atmospheric elements.

Interconnection between LAMs can be accomplished by use of optical fibre cables, specifically designed for rural networks where light weight and small dimensions contribute to low storage, handling and installation costs. Digital microwave and UHF radio systems can also be employed where the terrain and other economic factors make the installation of optical cable inappropriate
The RCS can interface with both analogue and digital switches provided that the switch signalling protocols are adequately defined and accsessible.

The key building blocks of the RCS are:

- Exchange interface equipment

- Local Access Module

- Optical and microwave transmission systems

- Network management systems

Figure 4 illustrates a typical interconnection of these building blocks.

SYSTEM EQUIPMENT DESCRIPTION

A Flexible Programmable Digital Multiplexer (PDMX) is the core of both the LAM and the exchange interface. It is essentially a primary digital multiplex equipment which forms up to 120 timeslots into a number of 2Mbit/s digital streams conforming to the CCITT format. Timeslot interchange between the 2Mbit/s streams is also possible, all under the remote control of the Network Manager, thus if a node has more than one link termination it can act as a drop and insert relay point with full re-routing capabilities.
Higher order multiplex cards can be used to combine 2Mbit/s streams into 8 and 34Mbit/s signals.

PDMX is a software based product, which enables easy upgrade to new services by

installing the appropriate software into the PDMX's control card. A range of Channel Associated Signalling (CAS) algorithms are available thereby giving tremendous flexibility in system applications for a wide range of networks. Subscriber configuration is carried out either locally by use of a hand held terminal unit or remotely by the Network Manager. The complete database for the PDMX control function is stored within the local PDMX control unit thereby ensuring security of information in the event of power loss to the equipment. The PDMX provides all the necessary interfaces for subscribers, transmission and remote management facilities for a complete node.
The line interface is at 2Mbit/s or with integral higher order multiplexers, 8 or 34 Mbit/s conforming to CCITT recommendation G.703. This provides the connection to the optical or radio transmission system or, with the appropriate signalling protocols direct to digital exchanges. The range of analogue interfaces available for the PDMX include earth-calling, loop-calling, direct dialling-in, E & M and magneto together with interfaces for data equipment . Signalling processors within the PDMX convert the various analogue signalling protocols to timeslot 16 signalling within the 2 Mbit/s traffic stream. Tone processors are also available which allow in-band signalling to be achieved where signalling transparency is required across the network. Remote management for the whole network of multiplexers and line terminating units is supported by an auxiliary maintenance channel which uses the spare bits within timeslot 0.

Optical transmission modules operating at bit rates from 2 to 34 Mbit/s are available which can be co-located with complementary second and third order (2-8 & 8-34 Mbit/s) multiplexers on the PDMX shelves. Alarms from these units as well as the tributary cards are processed by the PDMX controller and are therefore accessible by the network manager, enabling all aspects of the system to be remotely monitored, reported and logged.

The near universal use of singlemode optical fibres these days make this transmission medium more attractive than multichannel radio as increases in capacity can be easily achieved without major investment. The quality of fibre enables 2,8,34 140 and even 565 Mbit/s systems to use the same fibre types. As PDMX optical interface cards are totally interchangeable, system upgrade is usually achieved by merely changing the optical unit and associated higher order multiplex card. In contrast radio system upgrades frequently involve total replacement of the multiplex and R.F. equipments and even changes to the antenna system.

A major aspect in the provision of rural services is the requirement to provide buildings and power supplies. Hitherto the establishment of most systems have neccessitated the purchase of land for buildings and microwave towers together with associated services such as power, water,drainage and air conditioning. The small size and integrated approach offered by PDMX based systems enable the whole equipment for thirty subscribers to be located on a single shelf and for 120 subscribers to be accommodated on three or four shelves. This allows the remote equipment to be housed in small street cabinets, not much larger than those used for conventional subscriber distribution.

The Local Access Module designed for the rural system is based around a G.R.P. environmentally controlled street cabinet. The basic unit is capable of accommodating all the equipment and associated power plant to service up to 120 subscribers together with facilities for dropping 64kbit/s timeslots and regenerating 2, 8 & 34 mbits traffic streams to satellite LAMs in further rural areas (see Figure 4).
The cabinets are fully equipped with power supply systems and standby batteries capable of maintaining service for up to ten hours in case of failure of the public mains supply. When public mains electricity supplies are not readily available, the low power consumption makes solar power a reasonable option.

An external socket is provided for use when prolonged disruption necessitates the use of a portable generator.The temperature inside the cabinet is controlled by the use of both active and passive systems to ensure a safe working environment for the equipment. Alarms associated with power module, environment control and intruder alert can be extended back to the network control centre.

CONCLUSION

The requirement for a very flexible building block for a rural communications system can be met by a programmable multiplexer typified by the PDMX. When this is combined with low cost but high grade optical fibre links, compact freestanding equipment housings and a powerful network management system we have all the key elements for a communications system which can be changed and extended as demand and resources permit. A smooth upgrade path is possible without cost increments which are disproportionate with the increase in size of the user community and without making equipment redundant.

REFERENCE

1. Holden, G., Barnes, S.R., Stevens, D.L., Summers, A.T., 1988, Conference Proceedings on Rural Telecommunications, 23-25 May 1988.

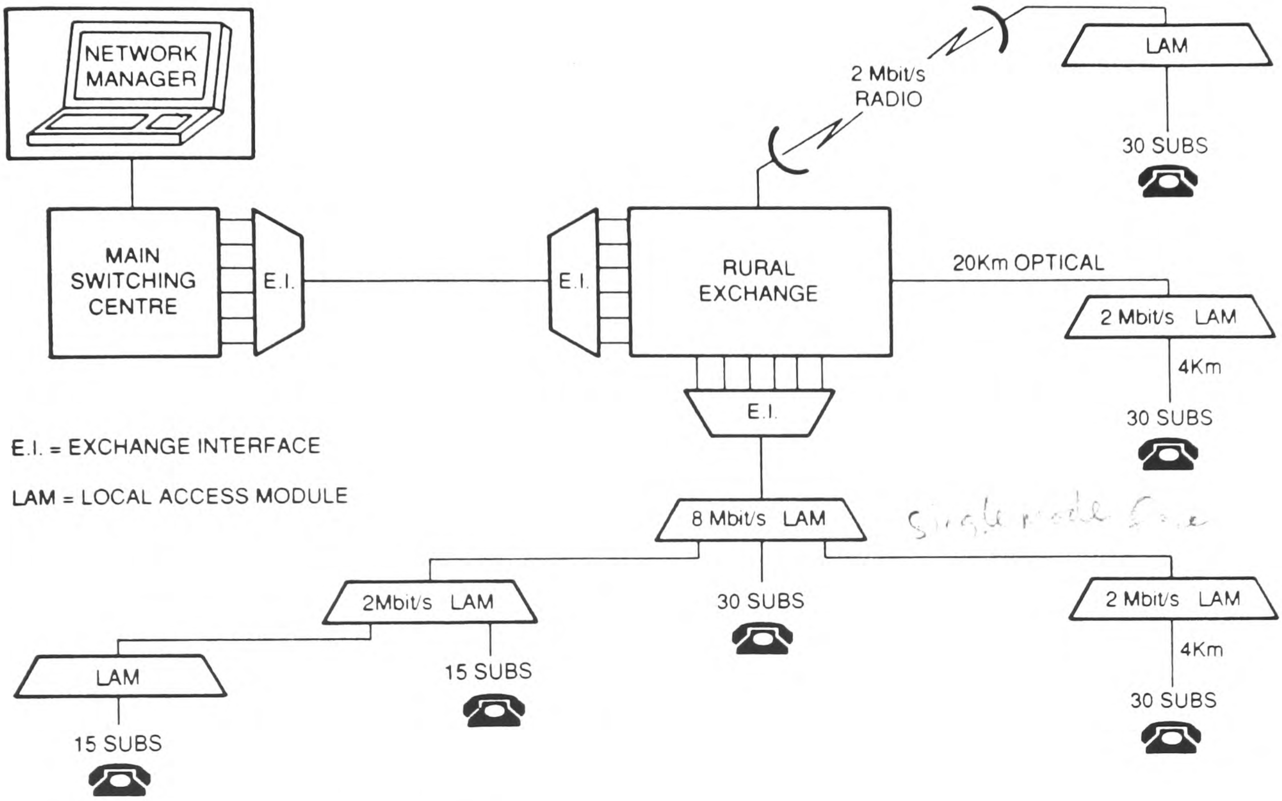


Figure 1 Topology of a Rural Communication System

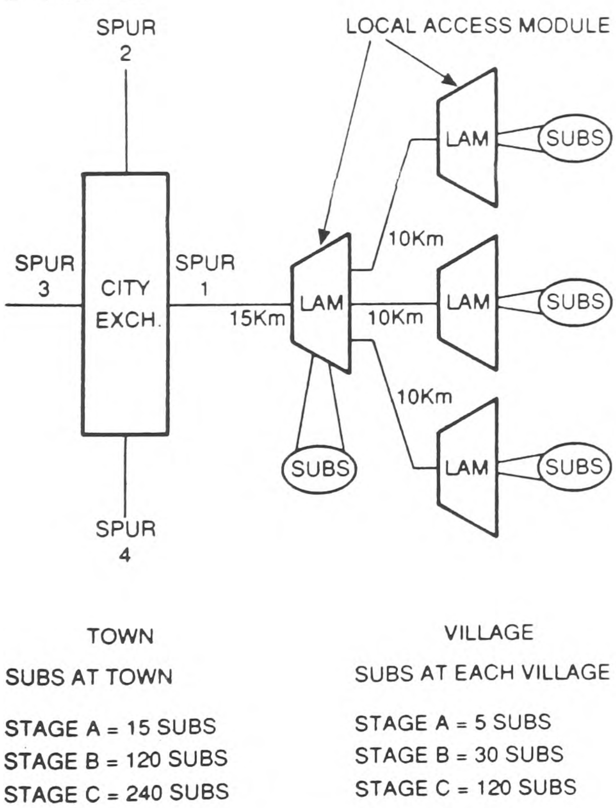


Figure 2 Rural Reference Model

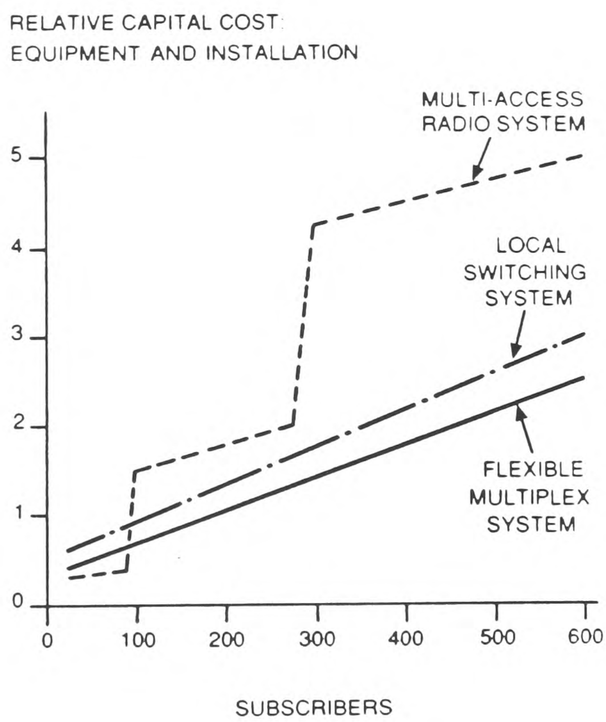


Figure 3 Comparative Cost Models

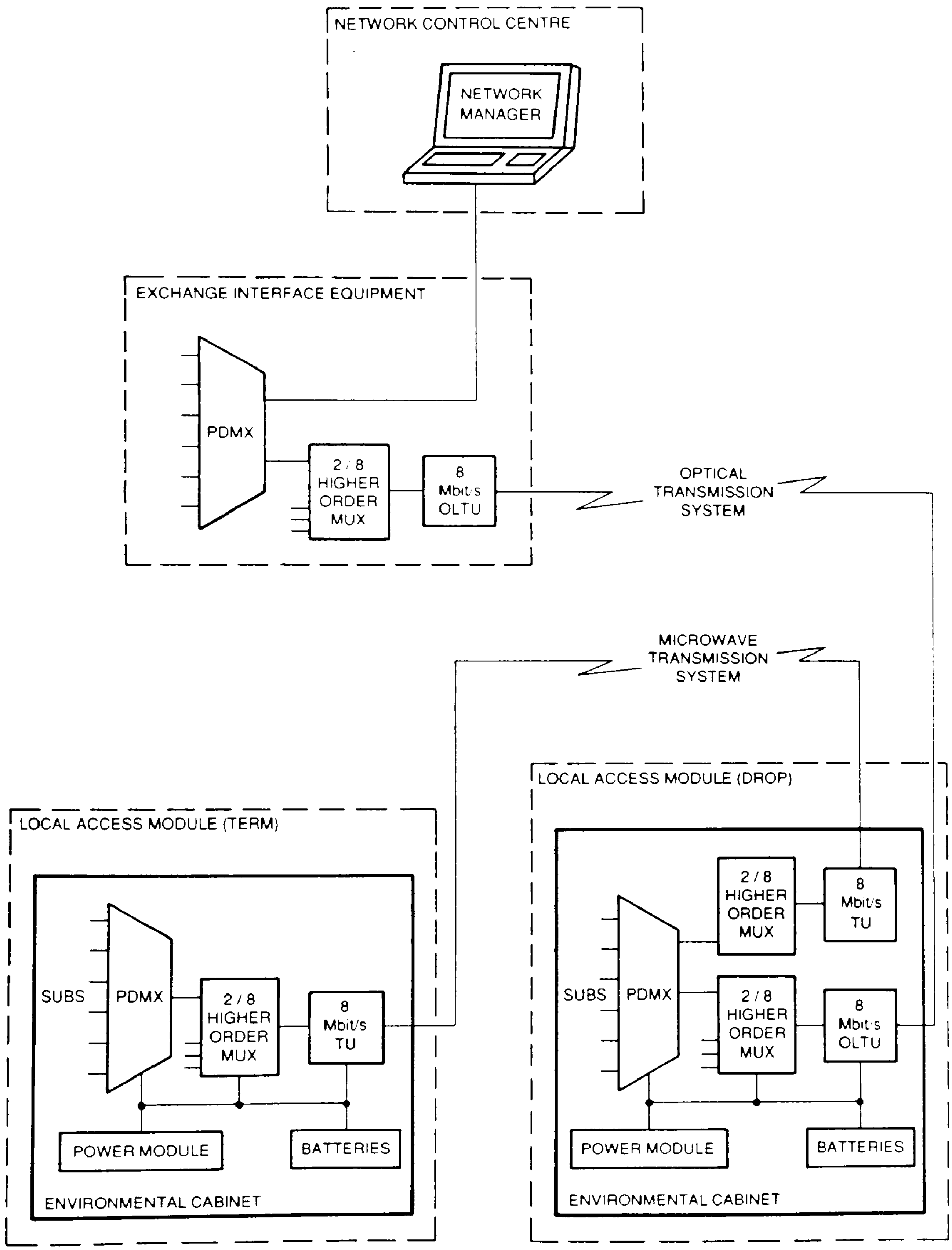


Figure 4 System Diagram of RCS

Appendix 3 The Solution to the Missing Link

THE SOLUTION TO THE MISSING LINK

A solution to the problem of rural telecommunications in developing countries using the STC Rural Communication System.

T. J. Pereira*, P. Sothcott', D. Waters', P. Davidson'

*STC Telecommunications Limited/Polytechnic of Wales
'Standard Telecommuncation Laboratories
'STC Telecommunications Limited

SLIDE 1

INTRODUCTION

The objective set by STC Telecommunications was to develop a cost effective telecommunication network, specifically designed for use in the rural regions of the world.

SLIDE 2 The often harsh climatic conditions, long transmission distances, uncertain subscriber traffic demands and often inadequate sources of electrical power provide an enormous challenge to network planners concerned with the provision of flexible telecommunication facilities to the rural areas of the world.

SLIDE 3 The Independent Commission for World Wide Telecommunications Development organised by the International Telecommunication Union and chaired by Sir Donald Maitland produced a comprehensive report entitled the "Missing Link" in December 1984 which emphasized the crucial need for communications to be established in order to encourage both economic growth and to aid political stability in developing nations of the world. There has been a growing awareness and concensus amongst the world's politicians and governments that the provision of reliable, cost effective and modern communication facilities would promote national and social cohesion and also encourage the establishment of rural industries. This should create employment for the rural communities and so discourage migration of the rural population towards congested urban cities.

The methods employed to provide communications to the rural area have traditionally been open wire carrier systems and time division multi-access point to multipoint radio. These methods have certain limitations in respect of flexibility and "stretch potential" and accordingly STC Telecommunications, in conjunction with STC PLC's research division, Standard Telecommunication Laboratories, have evolved a system based on optical fibre transmission and remotely located drop and insert subscriber units which, although primarily intended for speech, can be readily adapted to other forms of traffic.

SLIDE 4

SYSTEM OVERVIEW

The STC Rural Communication System is designed to function in harsh climatic conditions using appropriate environmental housings. The system enables a rural network to grow cost effectively from 30 to well over 400 subscribers. The use of optical cables in the rural areas contributes to lower installation and handling costs due to the small physical size and lightweight characteristics of the cable. The low power consumption of the communication electronics allows the use of solar or wind power modules, with back-up float charged batteries to provide both secure and economic sources of local power.

SLIDE 5

THE RURAL COMMUNICATION SYSTEM

The inherent bandwidth of the fibres enables the system to offer services other than telephony by the addition of appropriate equipment at the terminals. Facilities such as interactive slow scan television, ideal for educational use and remote health diagnostics can be readily incorporated into the system to extend information services to the rural population. The network can be established utilising any existing digital or analogue switch.

SLIDE 6 The system consists of:

- Exchange Interface Equipment
- Programmable Digital Subscriber Multiplexer (PDSM)
- Optical Line Systems including optical cables and connectors
- Network Management Systems

The block schematic of the system is shown in Figure 1.

SLIDE 7

EXCHANGE INTERFACE EQUIPMENT

The interface equipment shown in Figure 2 provides digital signals at 2 or 8 MBit/s conforming to CCITT recommendation G703 which is then transmitted on optical line cards to remote units known as Programmable Digital Subscriber Multiplexers (PDSM). The interface with an analogue exchange is achieved by working off the Main Distribution Frame (MDF) and that for a digital switch is through either 2 or 8 MBit/s digital ports. A range of subscriber signalling protocols such as 2 wire loop disconnect, E & M and various derivaties of common channel signalling are handled by means of software reconfiguration of PDMX's Non Volatile Random Access Memories (NVRAM) and its associated signal processing tributaries. The remote unit can be configured in a variety of ways including:

- simple multiplexer/demultiplexer
- a concentrator
- a small switch

The V24 interface on the mux control card of the software flexible Primary Digital Multiplexer (PDMX) enables the integration of the network management facility which handles the system alarms, maintenance functions and remote control of the rural network configuration.

System expansion can be achieved by several methods:

- Increase in transmission capacity from 2 MBit/s (30, 64 kBit/s channels) to

8 MBit/s (120, 64 kbit/s channels).
- Invoking the concentrator or switch options to cope with subscriber growth in the network.

LIDE 8* **PROGRAMMABLE DIGITAL SUBSCRIBER MULTIPLEXER (PDSM)**

The PDSM consists of the Primary Digital Multiplexer (PDMX), optical or copper line transmission systems, no-break DC power source using local supply, solar or wind power and an environmental shelter. The sub systems constituting the PDSM is shown in Figure 3 and Figure 4 shows the environmental housing used to house the equipment.

,IDE 9* The PDSM is capable of being used as a distribution node for onward transmission to other PDSM's located in the network on 2 MBit/s line rates with partially filled time slots. The PDSM is also able to extract the appropriate time slots and convert them into a suitable format for subscriber data or voice frequency telephony. The flexible nature of the main processor known as the mux control card of the PDMX enables this remote unit to evolve with subscriber growth. For initial low subscriber densities, the PDSM is configured as a normal multiplexer and further increase in demand for communication circuits can be met by the addition of the concentrator control unit and software adjustment of the PDMX. The PDSM is also able to migrate from a concentrator to a remote switch to offer both network resilience in case of cable breakage and reduce traffic congestion due to the outstations tromboning back to the central exchange to facilitate call set up.

The design philosophy used in the PDSM enables a low start up cost for the basic network which is capable of coping with future growth as the rural network increases both in terms of subscriber capacity and communication facilities.

DE 10* **OPTICAL CABLES AND OPTICAL LINE SYSTEMS**

A range of cables specifically designed for use in the rural environment are shown in Figure 5. Cables employed for both aerial and direct burial are shown. Metal-free optical cables are suitable for use in areas of high lightning strikes.
DE 11* These innovative cables are also suitable for co-installation with power lines thereby reducing installation costs by using existing poles or power grid towers. Metal-free cables are technically referred
DE 12 to as dielectric.* The dielectric direct burial cables are buried to approximately one metre depth using a plough or a trencher. In areas of hard rocky soil, the burial depth will be reduced. Termite and rodent attacks are prevented by the use of suitable sheathing materials over the cable. The rural optical cable's small diameter and extremely lightweight property enables up to 5 km of cable to be wound onto drums which are transportable on light vehicles to installation sites thereby reducing both handling and installation costs.

E 13* Table 1 indicates the comprehensive range of 2 to 8 MBit/s Optical Line Systems developed by STC. This optical line system family allows rural networks to be implemented for a range of transmission distances.

14* **NETWORK APPLICATIONS** Star configuration.

15* Linear straight spur configuration.

NETWORK MANAGEMENT SYSTEM

The PDSM's located away from central exchange requires the use of remote monitoring and prompt, accurate fault indication of the malfunctioning unit in the system. The central base maintenance philosophy used in the STC Rural Network allows the most efficient use of equipment and technical staff. The Network Management System consists of a desktop computer interfaced into the Rural Communication System via the V24 interface of the PDMX which is then able to communicate with all other parts of the system.

ECONOMIC ANALYSIS

To establish the economic viability of the new system, it was necessary to compare the cost of applying it to a typical situation with the costs incurred by traditional methods. The first step in this process was to evolve a reference model of a rural area. This was based on the ITU/CCITT GAS 9 study of a Rural Network in a developing country.

The model shown in Figure 6 postulates a "city" (A) in which the exchange is situated. Switching capacity for the rural area surrounding this city is achieved by running four spurs of average length 15 km to "towns" (B) and each town is then envisaged to provide communication links to three "villages" (C) at an average distance of 10 km from the towns. The towns are assumed to require a certain number of subscriber channels as well as providing onward distribution of the telecommunication facilities to the villages. The number of subscribers served by the model network is shown for three stages of development.

Year 0	:	Immediately following first installation 120 subscribers.
Year 10	:	840 subscribers.
Year 25	:	2400 subscribers.

SLIDE 16* For the purpose of the analysis, one of the four "spurs" shown in Figure 6 was isolated and used for the cost study.

Table 1 indicates the subscriber levels for the town and villages at three development stages.

TABLE 1

Year	Town (B)	Village (C)
0	15	5
10	120	30
25	240	120

The spur under study was divided up into number of quasi-independent "building blocks" consisting of areas of the system which have different functions as indicated in Figure 7.

Area A:	Equipment at exchange located in the city.
Area B:	Equipment located in the town.
Area C:	Equipment located in the village.
Area D:	Cable between city and town.
Area E:	Cable between town and villages.
Area F:	Subscriber distribution cable in the town.
Area G:	Subscriber distribution cable in the villages.

Three network solutions were considered and superimposed on the rural model. They were

- Multi-access radio.
- A conventional copper network.
- The STC Rural Communication System.

The multi-access radio solution required the installation of a central station interface equipment with an omni-directional aerial at the city exchange and remote radio outstations with directive aerials at the town and three villages. The initial subscriber demand was satisfied by installing a system operating at 1.5 GHz. To achieve the two further stages of growth, systems operating at 1.8 GHz and 2.1 GHz were added. Beyond the 300 subscriber level a high capacity radio system had to be implemented to cope with future subscriber growth. The conventional copper network employed digital transmission to a switch located in the town from where dedicated copper pairs were used to distribute telephony to the subscribers located both in the town and three villages.

The STC Rural Communication System employed a four 50/125 micron multi-mode fibre rural optical cable suitable for direct burial. This optical cable was used to connect both the city to the town and town to three outlying villages. Transmission was at 8 MBit/s from the exchange to town where a Programmable Digital Subscriber Multiplexer (PDSM) was used to drop and insert subscriber channels and also to provide three transmission paths at 2 MBit/s to the villages, where PDSM's were used to drop the subscriber channels. All of the PDSM's were housed in environmental shelters and would be provided with no break DC power supplies using solar power systems if no local electric power were available.

SLIDE 17* Figure 8 displays the results of the economic analysis.

The STC optical Rural Communication System is shown to be the most cost effective solution for the provision of telecommunication facilities to the rural area considered in this model.

The multi-access radio solution proved to be viable only in areas of low growth or where the terrain was unsuitable for the installation of cable. STC is currently exploring the possibility of integrating both a point to point and point to multi-point radio system to operate with optical cable based rural networks to offer greater flexibility to the network planner. The open wire carrier systems are unsuitable for use in this model due to their extremely limited expansion potential and lack of both quality and reliability of audio transmission.

SLIDE 18* SIMPLE SYSTEM SELECTION MENU

The cost savings and some non-quantifiable advantages of the STC Rural Communication System apply both to the initial installation and its subsequent expansion and lie in areas such as:

- Cheaper installation of cables in both city to town and villages due to lower handling and installation costs of the optical cable.
- The capability of the PDSM equipment located at the subscriber termination and distribution node to grow in a modular and cost effective way in respect of both new subscribers and new services.
- Low operating and maintenance costs due to the reduced use of outside plant such as regenerators which, in digital systems based on metal cable, are located approximately 3 to 4 kilometres spacing.
- Improved reliability due to the use of modern low power electronic equipment which also alows the use of independent remote powering options such as solar or wind power.
- The extreme flexibility of the concept, e.g.
  - Simple reconfiguration.
  - The ability to use analogue or digital exchanges.
  - The ability to accomodate radio distribution where desireable (say to isolated single subscribers or in areas hostile to cables.

OPTIONAL SLIDE 19, 20 * SYSTEM BLOCK SCHEMATICS USING 2 TO 8 MBIT/S

CONCLUSION

SLIDE 21* Optical fibre communication technology is well established in both the trunk and junction networks of many countries in the world. STC, backed up bY STL (the originator of the concept of optical fibre transmission), are world leaders in optical communication systems and are now able to supply rural optical communication systems which are capable of providing the most cost effective solution to problem of the "MISSING LINK" in rural areas of the world.

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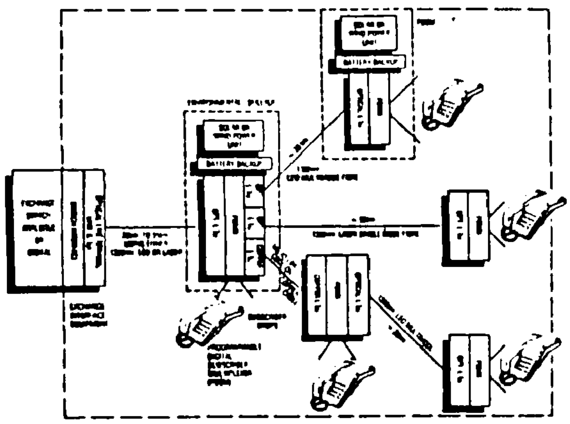


FIG. 1 STC rural network

FIG. 2 EXCHANGE INTERFACE

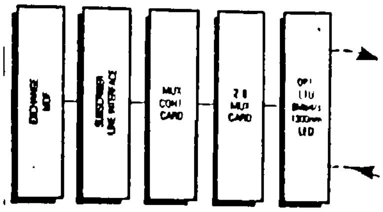
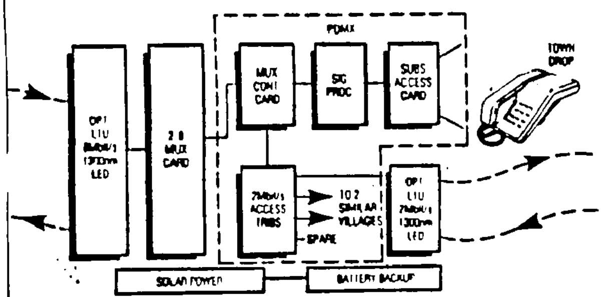
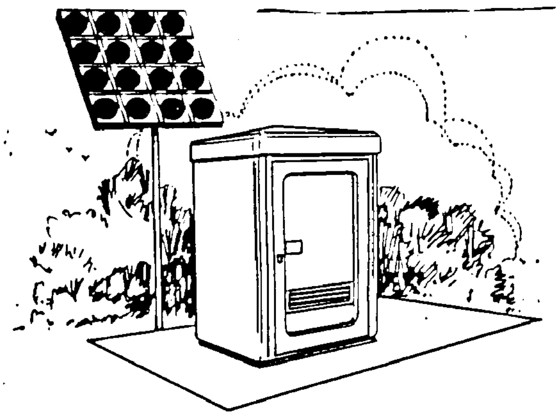


FIG. 3
PDSM USED AS A DISTRIBUTION NODE AND SUBSCRIBER CHANNEL TERMINATION



PDSM HOUSED IN ENVIRONMENT SHELTER FIG. 4



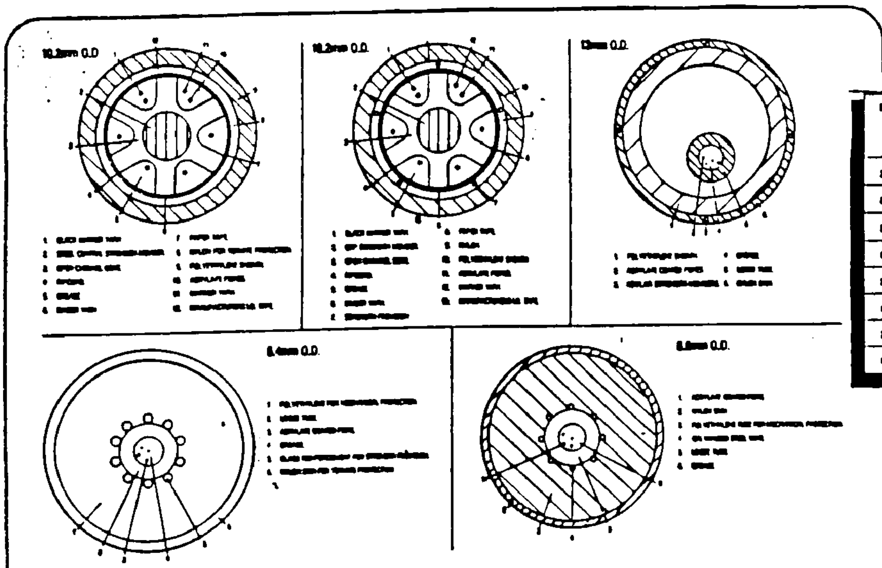


FIG. 5 Rural area cables

TABLE 1

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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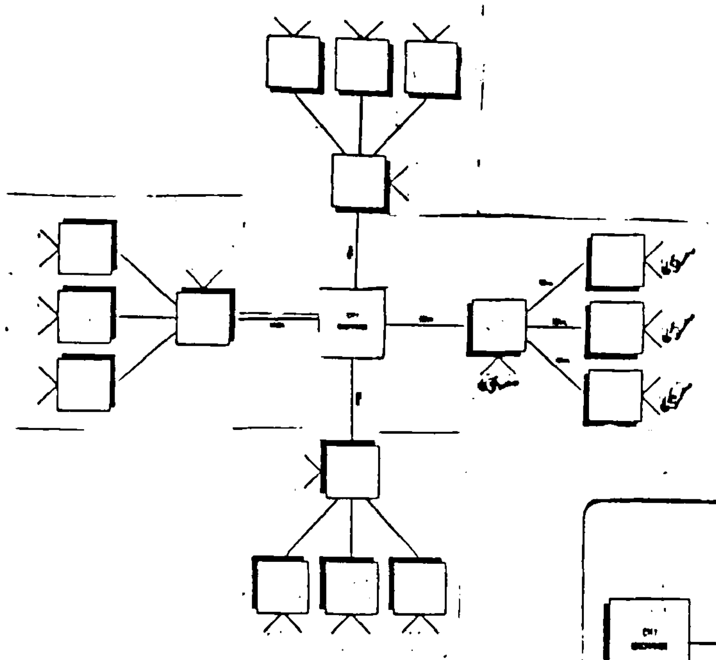
FIG. 6



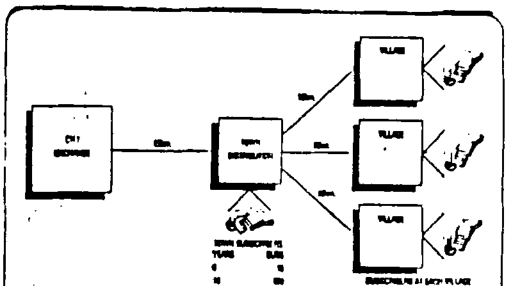


FIG. 7 Cost analysis model derived from ITU/CCITT Gas 9 rural network study

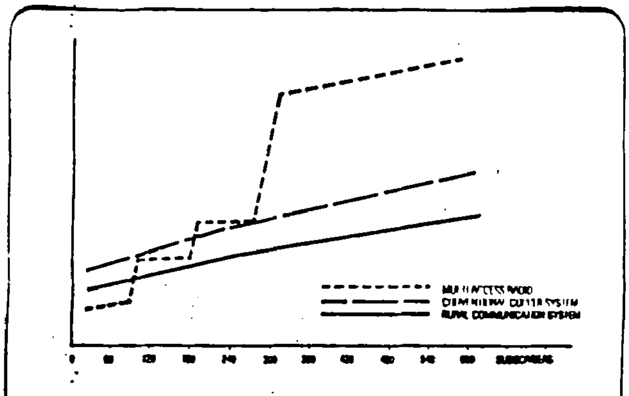
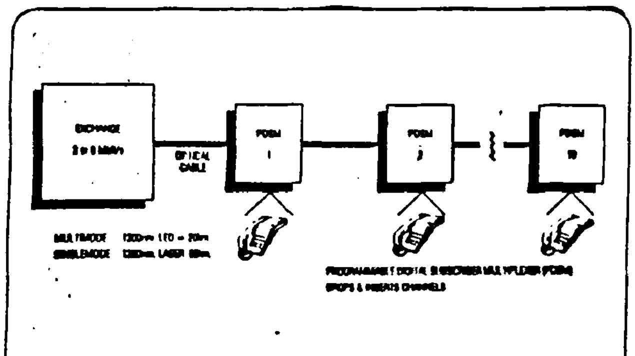
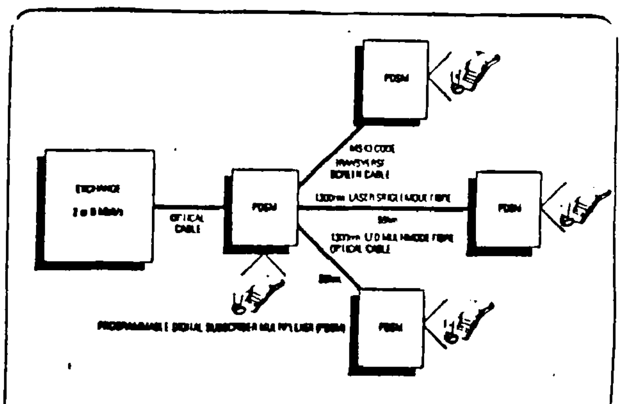


FIG. 8 Display of cummulative system cost



Straight spur configuration



Star configuration

NETWORK APPLICATIONS.

References

1. ITU/CCITT GAS 9 Case Study on a Rural Network, Geneva 1982, International Telecommunications Union.

2. Telecommunications for Development, ITU/OECD, June 1983.

3. New Technologies and Services, ITU World Communications Year Seminar Meeting, Kuala Lumpur, Malaysia 5-8 December.

4. Public Communication Networks in Rural Areas of Developing Countries, P.Sothcott/T.Pereira 1984

5. ITU/CCITT Rural Telecommunications Supplement No.1 Geneva 1983, ITU.

6. Photovoltaic Power System Design for Telecommunications, I.F. Garner 1985.

7. Installation of Optical Fibre Cables, Sune Edman, Ericsson Review 1984.

8. The Missing Link, Report of the Independent Commission for Worldwide Telecommunications Development, International Telecommunications Union, 1984 December.

9. Rural Networks, Providing System Solutions, STC Telecommunications May, 1984.

10. Turnkey Optical Subscriber Communication Systems, Teaching Company Report, T.J. Pereira, 9/January/1985.

11. RC 5000M Environmental Specifications, British Telecom, UK 1984.

12. Signalling Systems, S. Welch.

13. Solution to the Missing Link, FODC Conference, Yugoslavia 1985.

14. BTNR 315,306, BT UK Signalling Significations.

15. Market Research Plan (MRP), CIT 1985.

16. Telecommunications Dollar, 1985.

17. ITI Market Intelligence Information, 1985.

18. Flexible Rural Systems, T.J. Pereira, May 1988, IEE Rural Telecommunications Conference (Appendix 3)

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